Copyright 1927, by the AMERICAN SOCIETY OF NAVAL ENGINEERS.

JOURNAL
OF THE
AMERICAN SOCIETY OF NAVAL ENGINEERS

VOL. XXXIX. AUGUST 1927. No. 3

The Society as a body is not responsible for statements made by individual members

COUNCIL OF THE SOCIETY
(Under whose supervision this number is published).

Rear Admiral JOHN HALLIGAN, Jr., U.S.N. Rear Admiral C. W. DYSON, U.S.N.
Captain E. L. BENNETT, U.S.N. Captain Q. B. NEWMAN, U.S.C.G.
Commander O. L. COX, U. S. N. Lieut.-Comdr. E. L. COCHRANE, (C.C.) U.S.N.
Mr. J. F. METTEN Mr. H. M. SOUTHGATE
Commander H. B. HIRD, U.S.N.

TACHOMETERS, REVOLUTION INDICATORS, SPEED INDICATORS AND REVOLUTION COUNTERS. TYPES AND PRINCIPLES OF OPERATION.

BY C. HUEY, CIVIL MEMBER.*

There is perhaps no more elusive device in Naval Service than one which will accurately indicate the speed of a moving body or a shaft, for long priods of time, unaffected by deterioration or by external conditions. There has existed considerable controversy as to the desirability or necessity for the accurate indication or recording, of the speed of propeller shafts in Naval Service. As with all measuring devices, the economy, reliability and control of any or all operations, is greatly enhanced by the maintained accuracy of the instruments on whose dependence the operations are carried out. It is still debatable as to whether accurate knowl-

* Material Engineer, U. S. Navy Yard, New York, N. Y.

edge is required as to the daily or trip log of the ship's propellers, the division of load between multiple propeller shafts, the average shaft revolutions per minute of a ship in fleet formation, the maintenance of fixed cruising speeds, or the maximum developed shaft revolutions under various conditions of the hull or the elements. It cannot be gainsaid, however, that as a matter of general engineering principles, any or all measuring devices, whether they be yard-sticks or chronometers, should have the element of accuracy and reliability to such a degree that any change in operating conditions should be faithfully measured. Conversely, any change in the recorded measurements should reliably foreshadow or disclose a change in operating conditions.

For many years inventors and manufacturers have produced various forms of speed indicating devices incorporating different principles of operation, with the general idea in mind, to evolve a reliable simple device, free from appreciable errors and unaffected by service conditions. This article will describe the numerous types which have been offered or used in Naval Service and will discuss the advantages, disadvantages, application, usefulness, and the general principles and functions involved.

Definitions. For the purpose of classification, devices for indicating or counting revolutions per minute of a revolving shaft, or indicating the speed or velocity of a moving object based on shaft revolutions, are defined as follows:

Tachometer, derived from the Greek word tachos, meaning swiftness, is an instrument to indicate the velocity and change in velocity of a moving body, or to indicate the rate of rotation and change in rate of rotation of a revolving shaft. In order to adhere strictly to this definition, it is to be expected that only such types of instruments whose indications will inherently follow closely the accelerations and de-accelerations of a moving body or a shaft, should be classified as tachometers.

A Revolution Indicator is defined as a device which can periodically or continuously, indicate the rate of rotation of a shaft, but due to inherent limitations, does not follow closely or indicate the acceleration or de-acceleration of the shaft as do tachometers.

A Speed Indicator is defined as a device which can periodically or continuously, indicate the rate of speed of moving body. This

rate may be based on the rate of speed of a moving shaft which is the cause of the speed of the body, but when the indications are in terms of the movement of the body, it is defined as a Speed Indicator. Under this definition would be placed Speedometers, which indicate the speed of vehicles based on the shaft revolution of some part of the driving mechanism, or the speed of ships in knots, or nautical miles per hour, based on their movement through the water, or, on the revolutions of the propeller shaft.

A Revolution Counter is defined as a device which numerically counts the number of revolutions of a shaft continuously or for a period of time. The rate of speed of the shaft in revolutions per minute, therefore, cannot be determined without the use of a timing device. A revolution counter in combination with an automatic timing device, is classified as a revolution indicator.

CLASSIFICATION.

Under the above definitions of tachometers, revolution indicators, speed indicators and revolution counters, it should be possible to classify various types in terms of Application or Results. However, in order that there may be a basis for such classification, and to better analyze the probable results to be expected under definite applications, the various types are classified as to Principles of operation as follows:

Class 1. Centrifugal, mechanical, revolving wheel.

Class 2. Centrifugal, mechanical, revolving weights, Governor Type.

Class 3. Resonant or Vibrating Reeds, mechanical.

Class 4. Resonant or Vibrating Reeds, electrical.

Class 5. Chronometric, mechanical.

Class 6. Mechanical, positive drive.

Class 7. Electrical, positive drive.

Class 8. Chronometric, electrical.

Class 9. Magnetic, electrical.

Class 10. Magneto-generator, electrical.

This group of devices are further classified as to form of generator and indicator as follows:

(A) Direct current magneto-generator with direct current voltmeter form of indicator.

(B) Alternating current magneto-generator with induction wattmeter form of indicator.

Class 11. Combination Mechanical-Electrical Systems.

Class 12. Combination Electrical-Chronometric Systems.

Class 13. Pulsator System, Electrical.

All the above types of devices are supplied either for portable use, or for stationary or fixed installation, or for both classes of applications.

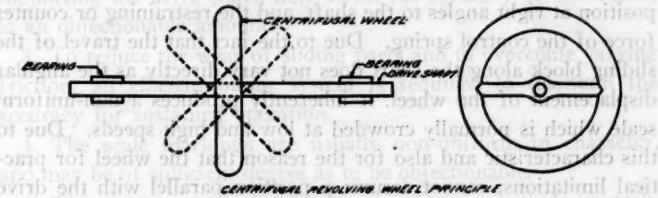
From the basic definition of tachometers, revolution indicators, speed indicators, and revolution counters, it is evident that the correct term to designate the various types should be based on performance and application. There appears to be no standard terminology used, and some confusion exists as to the distinction and basic performance of the various types described.

In order to obtain the desired results in the use of this group of measuring devices, a close study is necessary as to the general accuracy, the effects of wear or lack of lubrication, ease and permanency of adjustment. Additional consideration must be given on Stationary Mechanical types, to the practicability of distant or multiple recording; on Stationary Electrical types, to the effects of multiple indicators on one another, of magnetic stray fields, of variable line or contact electrical resistances, of variable or extreme temperatures; on Portable types, to the weight, compactness, and versatility as to application and speed ranges.

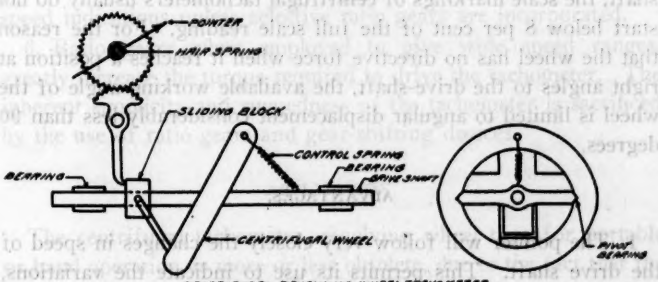
The remainder of the article will be devoted to the detailed description of various types, and photographic illustrations are furnished of various representative devices offered to the Navy from time to time. While there are possibly many other forms of speed indicating or revolution counting devices in general service, attempt has been made to describe and illustrate on the basis of fundamental principles. Therefore any remarks or criticisms are to be construed on this basis rather than on the quality of the brands selected as representative of its classification.

CLASS 1.—CENTRIFUGAL TACHOMETERS, MECHANICAL, REVOLVING WHEEL TYPE.

Probably the oldest practical form of tachometer still in use is known as the centrifugal (revolving wheel) type. The principle of operation as indicated by name, is dependent on the centrifugal force exerted by a rotating mass of appreciable rim weight, to cause the mass to assume a position at right angles to the axis of its supporting and rotating shaft, as shown in Figure No. 1. The application of the above principle to the tachometer, is shown in Figure 2, and illustrated by plate No. 3.



CENTRIFUGAL REVOLVING WHEEL PRINCIPLE
FIG. 1



CENTRIFUGAL REVOLVING WHEEL TACHOMETER
FIG. 2

EXPLANATION.

The revolving mass elements in the form of a balanced weighted wheel, is carried on the main drive shaft of the tachometer, by means of a cross-shaft having pivoted supports. These supports allow a freedom of motion of the weighted wheel, to assume angular positions in regard to the main shaft which rotates it. The rim of the wheel is linked with a cross-head, which is free to

slide on the shaft as the wheel assumes different angular positions. The indicating mechanism consists of a pivoted pointer with a hair-spring used as a control force, geared to a sectored lever arm in contact with the sliding block. Normally the wheel would assume a position at right angles to the shaft at a low speed sufficient only to develop directive force to overcome friction of the parts. It is, therefore, necessary to employ a control spring as a counter force, to hold the wheel in angular positions as the shaft revolves at higher speeds when used as a tachometer. The position of the pointer in relation to the speed of the shaft, is the resultant of the centrifugal tendency of the wheel to assume a position at right angles to the shaft, and the restraining or counter force of the control spring. Due to the fact that the travel of the sliding block along the shaft does not vary directly as the angular displacement of the wheel, it inherently produces a non-uniform scale which is normally crowded at low and high speeds. Due to this characteristic and also for the reason that the wheel for practical limitations, cannot assume a position parallel with the drive shaft, the scale markings of centrifugal tachometers usually do not start below 8 per cent of the full scale reading. For the reason that the wheel has no directive force when it reaches a position at right angles to the drive-shaft, the available working angle of the wheel is limited to angular displacement considerably less than 90 degrees.

ADVANTAGES.

1. The pointer will follow very closely the changes in speed of the drive shaft. This permits its use to indicate the variations, pulsations, or jump in speed of machinery shafting in addition to indicating the settled speeds.

2. Due to its principle of operation, few mechanical parts are required, and these may be appreciable in size and rugged in construction.

3. The deflection of the pointer is inherently in one direction regardless of the direction of rotation of the drive shaft, thereby permitting the use of a simplified scale.

DISADVANTAGES.

1. The permanency of calibration is dependent on the permanency of the control spring, and the effective length of the lever arms connecting the moving parts to the index pointer. Due to the fact that the principle of operation requires the employment of rotating mass of appreciable weight, mechanical wear of various bearings is to be expected. This in turn changes the effective length of the lever arms and results in change in calibration.

2. Varying friction in the sliding block, in the gears to the pointer, in the pivots or in any of the bearings, other than those supporting the drive shaft, may affect the accuracy of calibration to an objectionable amount.

3. To reduce the wear of sliding parts and to overcome varying friction, an efficient oiling system is required to maintain the accuracy for sustained operation.

4. The scale markings are usually non-uniform in character, and may be of sufficient degree as to be objectionable.

5. There exist practical difficulties in obtaining a wide range in speed indications unless selective ratio gears are incorporated.

6. Ratio gears when employed to give wide speed ranges, greatly increase the torque required to drive the tachometer. The inherent simplicity and ruggedness of the tachometer is sacrificed by the use of ratio gears and gear-shifting devices.

APPLICATION.

The centrifugal tachometer, revolving wheel type for portable or hand operation, is more or less obsolete, due to the fact that the revolving weight type has been developed for the same applications. This latter type, as developed, has the advantage of being more compact and lighter in weight. For stationary or fixed installations, the revolving wheel type, when belt driven, is used for indicating the normal steady running speed of machinery where only ordinary accuracy is required, where the speed is moderate, and where the indicator can be mounted in close proximity.

CLASS 2.—CENTRIFUGAL TACHOMETERS, MECHANICAL, REVOLVING WEIGHT, GOVERNOR TYPE.

The revolving weight, or governor type, centrifugal tachometer, is somewhat similar in general details, to the weighted wheel type described under class 1, with the exception, that the moving force is that of revolving hinged weights which tend to fly out from the center of rotation, by virtue of the centrifugal force exerted by

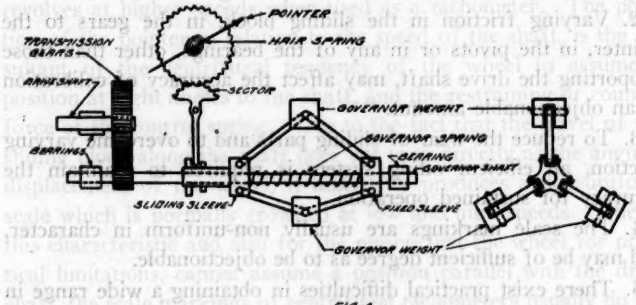


FIG. 4.

CENTRIFUGAL, REVOLVING WEIGHT, GOVERNOR TYPE, TACHOMETER

rotating masses. The diagrammatic scheme is shown in Figure No. 4. Plate No. 5 shows the application of this type of device for indicating the peripheral speed of revolving surfaces. Plate No. 6 illustrates a single range tachometer, and Plate No. 7 illustrates a triple range tachometer.

EXPLANATION.

The revolving element, in one form shown in Plate No. 7, consists of four balanced weights, revolved by the drive shaft of the tachometer, similar in principle to the fly ball governor common to power-house steam engines. The centrifugal action of the weights is restrained by the counter-action of spiral control springs. The resultant displacement of the supporting weight links is transmitted through a system of levers and gears, to the indicating pointer. In the form shown in Plate No. 6, the element consists of three balanced weights, hinged to a sliding block on

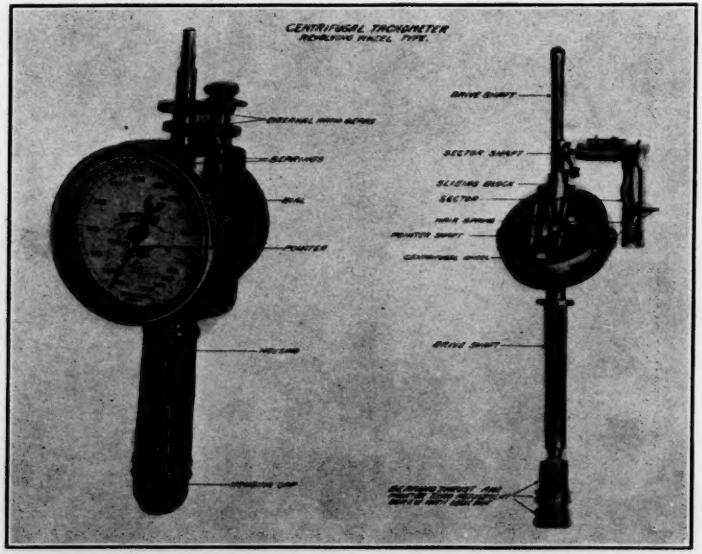


PLATE NO. 3.

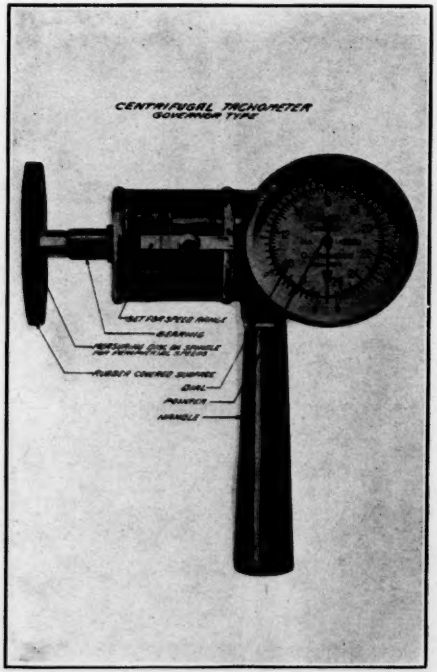


PLATE NO. 5.

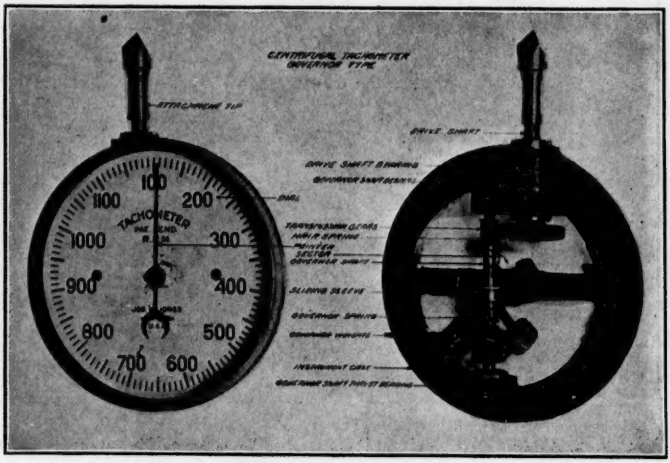


PLATE No. 6.

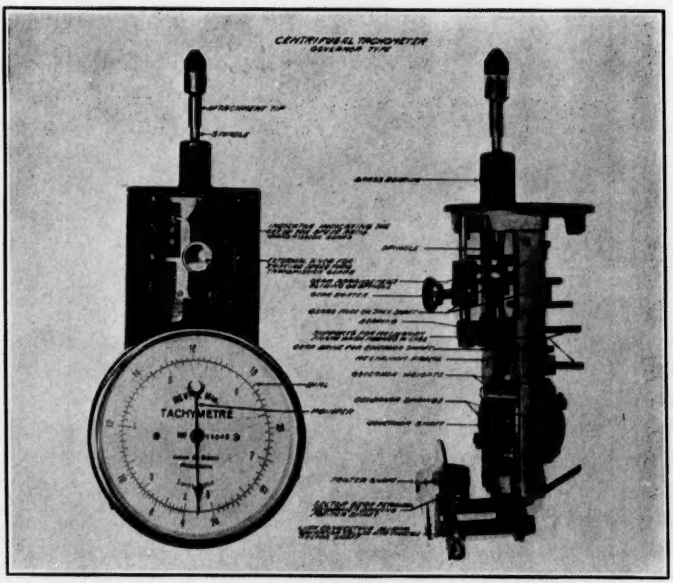


PLATE No. 7.

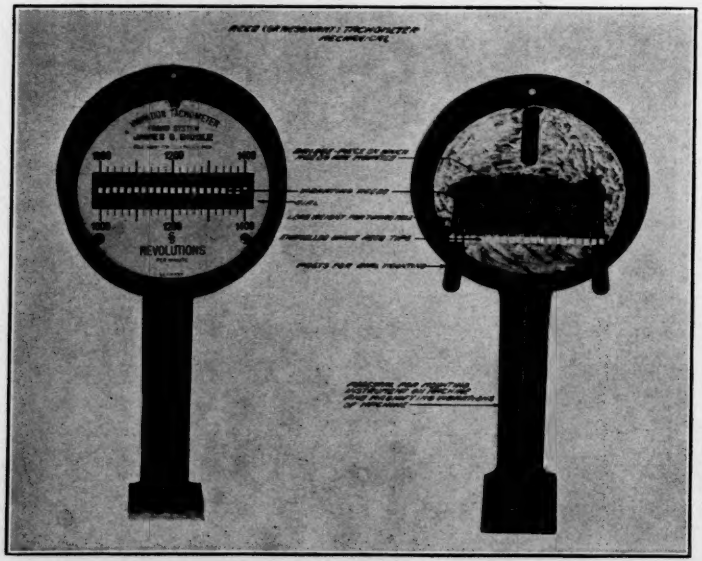


PLATE No. 9.

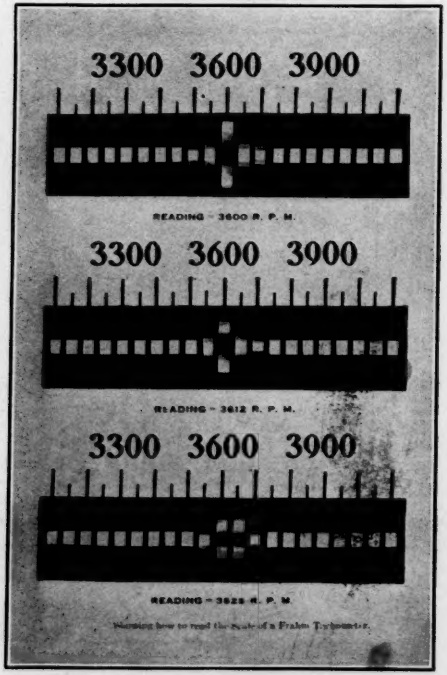


PLATE No. 10.

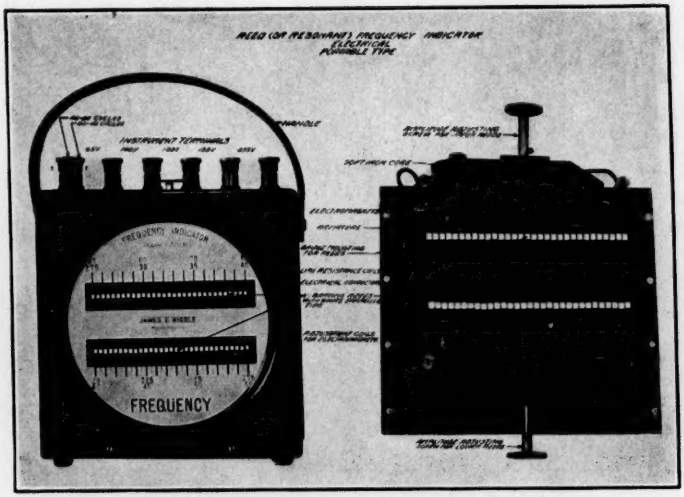


PLATE NO. 12.

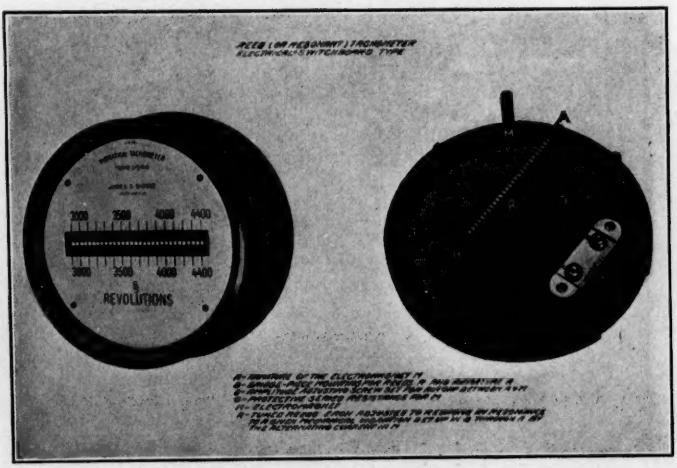


PLATE NO 12A.

the governor shaft, and restrained by the counter-action of a helical control spring. This form represents a recent development in centrifugal tachometers, the principle features being the geared-up, light-weight governor element, and a compensated link motion, which results in a very uniform scale at all speeds within its range.

The Advantages, Disadvantages, and Application of the governor type centrifugal tachometers, are practically as outlined for the revolving wheel type, class 1, except that the weight of the revolving elements is greatly reduced, thereby decreasing the inherent friction and the drive torque required. On the geared-up, governor type, the developments have been along the lines of single range, ball bearing, high speed, light-weight mechanisms, which develop uniform scales and incorporate readible indications over a wide range of speeds.

CLASS 3.—REED (OR RESONANT) TACHOMETER, MECHANICAL.

This group of tachometers for use on fixed installations, or for hand operation, is unique both in principle of operation and method of indication. The speed is shown by the vibration of certain units in a row of tuned steel reeds which are shown in Figure 8, and

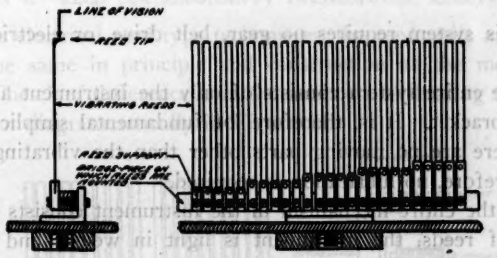


FIG 8.

REED (OR RESONANT) MECHANICAL TACHOMETER

which are seen through an opening in the scale plate of the instrument, illustrated in Plate No. 9. The hand type is made with a plain case and indications are obtained by holding the instrument against some part of the machine under test.

EXPLANATION.

The operating principle is that of resonance, which may be described as follows: If a reed, tuned to vibrate a given number of times per minute, is subjected to the influence of a body vibrating even but slightly at the same rate, the reed will be thrown into considerable vibration. As it is impossible to perfectly balance any machine which contains rotating parts, each revolution causes a distinct impulse or vibration. If a frame supporting a series of tuned reeds is clamped to a machine which is in operation, that reed will respond which is tuned nearly to the same rate of vibration. The scale at the point opposite this reed is marked with the corresponding R.P.M. so that the shaft speed is indicated thereby. Plate No. 10 illustrates the appearance of the vibrating reeds at different degrees of resonance. As the dynamic balance of modern machinery has been carried out to a high degree, it is sometimes necessary in installing the mechanical reed type tachometer on such machinery, to amplify the vibrations transmitted by the machine to the tachometer by means of an amplifying weight overhung on the back of the instrument.

ADVANTAGES.

1. This system requires no gear, belt drive, or electrical connections.

2. The entire system consists of only the instrument and supporting bracket. It is, therefore, of fundamental simplicity.

3. There are no moving parts other than the vibrating reeds, and, therefore, no lubrication is required.

4. As the entire mechanism in the instrument consists only of a row of reeds, the instrument is light in weight and readily mounted for installation.

DISADVANTAGES.

1. Due to the practical limitation of the number of tuned reeds employed, it is necessary, except on cardinal points, to interpolate or estimate the corresponding R.P.M. indicated by two or more adjacent reeds vibrating at different amplitudes as illustrated in Plate No. 10.

2. There can be no means employed to indicate the direction of rotation.

3. The tuned reeds may pick up and register vibrations of adjacent machinery within the range of the instrument.

4. It is difficult to adjust and maintain a satisfactory amplitude or reed vibration, due to the varying amplitude of vibration of the machine caused by increasing bearing wear, and unbalanced conditions due to unequal wear of rotating members in the machine.

5. The reeds in the instrument are subjected to serious bending stresses if for any reason their amplitude of vibration is excessive.

6. Practical limitations of the number of reeds employed results in a narrow range of speed indication.

7. Distant recording or multiple indicators can not be employed.

APPLICATION.

The use of the mechanical reed type tachometer is chiefly for installations on prime movers running at a basic governed speed, where direct application can be made to gain simplicity and low cost of installation.

CLASS 4.—REED (OR RESONANT) TACHOMETER, ELECTRICAL.

In the electrical reed type tachometer, the reed units are essentially the same in principle and construction as the mechanical type. The chief difference is in the method of vibrating the reeds as shown diagrammatically in Figure 11.

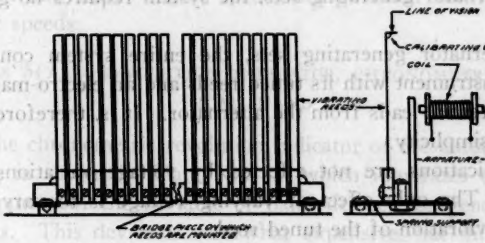


FIG. 11

REED (OR RESONANCE) TACHOMETER ELECTRICAL TYPE.

EXPLANATION.

In the electrical type the excitation of the reeds is produced from a simple form of electro-magnet mounted in the instrument adjacent to the reed-comb, and excited by the alternator voltage of the machine-driven set whose speed is to be indicated. In this system the speed of the alternator or prime mover may be indicated in terms of frequency of A.C. alternations as shown in Plate 12, or in R.P.M. of the prime mover as shown in plate 12A, based on the equation

$$f = \frac{P \times R.P.M.}{60} \text{ or } R.P.M. = \frac{f \times 60}{P}$$

where f = the frequency in cycles per second and
P = the number of pairs of magnetic poles of the alternator.

The electrical type can be applied to indicate the speed of machinery other than alternating current generating sets, by employing a small belted or geared magneto type alternator, as a source of excitation for the indicator. In this system the ratio of the inherent magneto alternations and its driven speed, needs be coordinated, to produce the correct indications on the indicator corresponding to the machine speeds.

ADVANTAGES.

1. For alternator generating sets, the system requires no gears or belt drive.

2. For alternator generating sets, the entire system consists of only the instrument with its tuned reeds and an electro-magnet excited by potential leads from the alternator. It is, therefore, of fundamental simplicity.

3. The indications are not affected by voltage variations or stray fields. The only effect of varying voltage is to vary the amplitude of vibration of the tuned reed.

4. The accuracy of indications is not affected by contact resistances, stray magnetic fields, temperature changes or varying length of potential leads to the indicator.

5. The indicator can be installed at any reasonable distance from the machine and multiple indicators can be employed without affecting their accuracy.

6. The amplitude of vibration of the reeds can be readily adjusted at the indicator by increasing or decreasing the magnetic air-gap.

DISADVANTAGES.

1. Due to practical limitations of the number of tuned reeds employed, it is necessary, except on cardinal points, to interpolate or estimate the corresponding R.P.M. indicated by two or more adjacent reeds vibrating at different amplitudes, as illustrated in Plate 12A.

2. There is no means employed to indicate the direction of rotation.

3. The reeds in the instrument are subjected to serious bending stresses, if for any reason their amplitude of vibration is excessive, such as would be caused by excess voltage or improper air-gap adjustment.

4. Practical limitation of the number of reeds employed results in a narrow range in speed indications.

APPLICATION.

The use of the electrical reed type tachometer is chiefly for installation where only nominal plant alternating frequency is required and where engine speeds are governor controlled to give basic speeds.

CLASS 5(A). REVOLUTION INDICATOR, CHRONOMETRIC, MECHANICAL, HAND TYPE.

The chronometric revolution indicator of the automatic counter type, is shown in Plate No. 13, which illustrates the latest development of the portable or hand device, for general test purposes. This device is somewhat expensive, but due to its wide range of application, it is considered to be an important addition to list of instruments for determining the rate of speed of revolving shafts.

EXPLANATION.

The operating principle is, in general, that of a mechanical revolution counter, in combination with an automatic chronometric device which starts, counts the number of revolutions for a definite interval of time, stops, and indicates the same on the dial, in terms of the number of revolutions per minute. The details of the mechanical arrangement of this device are shown in Figure No. 14.

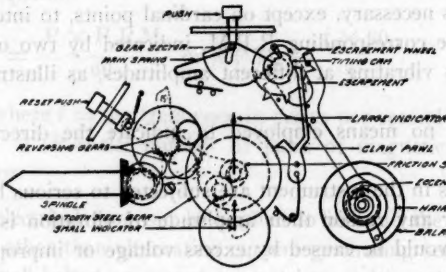


FIG 14

CHRONOMETRIC MECHANICAL REVOLUTION INDICATOR
HAND TYPE

THE SPINDLE AND GEAR SYSTEM.

The spindle drives, through a steel gear at the inner end of the spindle, a brass bevel gear, two reversing gears, and a train of reduction gears that operate the 1,000 and 10,000 pointers. The direct reading (1,000) gear, is held by a flat tension spring, against a steel gear having 200 teeth. The long pointer is attached to the gear which is prevented from turning in common with the brass gear, by means of a claw pawl which engages the teeth in the form of a ratchet engagement maintained by the pressure of a helical spring. A shoulder on the ratchet wheel lays against the brass gear of the reduction train and constitutes a friction drive for the indicator. When the pawl engages the ratchet wheel, the wheel remains stationary, and there is a continuous sliding movement between the shoulder of the ratchet wheel and the brass gear when the train of gears and spindle are revolving.

THE TIMING SYSTEM.

By depressing an exterior button attached to a shaft, a sector gear is turned through an arc of about 45 degrees, and against W shaped main spring. As the spring gradually releases, it drives the sector gear, which in turn drives the escapement of a watch movement. This movement has a balance wheel and hair spring. Rigidly attached to the shaft of the escapement wheel, is a circular cam with about ⅓ the circumference milled down to a smaller diameter. A claw shaped pawl tightly engages the outer surface of the cam. The same pawl has a claw which engages the steel ratchet wheel. When the claw engaging the cam is forced out by the projection on the cam, the other claw disengages the ratchet wheel and allows it to turn at the same speed as the gears, by means of the friction drive. The main spring and gear sector, are designed to operate for about 5 seconds. When the main spring is released, the watch movement immediately starts and comes to full speed in one second, at which time the projection on the cam, causes the claw to release the ratchet wheel, and the pointer starts traveling. At the end of 3 seconds, the cam causes the claw to engage the ratchet wheel, and the pointer stops and indicates directly the R.P.M. of the spindle.

Although this arrangement appears somewhat intricate, the parts are fabricated equal in accuracy and fit, to that of a chronometric watch, and the general reliability, repair and upkeep is of the same order. The chronometric device is automatically rewound during the starting operation. The starting and stopping errors of the timing device are eliminated in the design, by reason of the fact that the timing gears automatically function a few seconds before the counting starts, and continue for a few seconds after the indications are recorded.

ADVANTAGES.

1. Is self-contained, small size and light weight.
2. Requires very little driving torque.
3. Has no starting or stopping errors.
4. Is not affected by magnetic stray fields.
5. Accuracy of counting is of high order on par with that obtained by chronometer watches.

6. Applicable to all ranges of speeds, and indicates clearly.

7. Indicates Revolutions Per Minute, in an elapsed time of about 5 seconds.

8. Mechanical wear of parts does not primarily affect the accuracy of calibration.

9. Has uniform scale graduations.

10. Indicating pointer remains at the indicated reading until re-set to zero by the operator, thus permitting readings in otherwise inaccessible locations.

DISADVANTAGES.

1. Will not indicate instantaneous rates of speeds, or peak speeds.

2. Will not indicate accelerations or de-accelerations in rate of speed.

3. Repairs or adjustments can readily be made only by the manufacturer of the instrument.

APPLICATION.

The hand type chronometric mechanical revolution indicator, or automatic revolution counter, is primarily for use in general test purposes, where high maintained accuracy is required, and where the average rate of speed during a five second interval is representative of the performance of the shaft under test.

CLASS 5(B).—REVOLUTION INDICATOR, CHRONOMETRIC, MECHANICAL, SWITCHBOARD TYPE.

The mechanical chronometric revolution indicator, of the averaging, continuously indicating, switchboard or fixed type, is shown in Plate No. 15, which illustrates a development for indicating the engine speed of aeroplanes. This device is driven from the engine shaft, by means of a pinion, gear and flexible metallic shaft, connected direct to the indicator. All parts of this device are entirely mechanical.

EXPLANATION.

The operating principle, in general, is that of an averaging revolution counter, in combination with an automatic chronometric

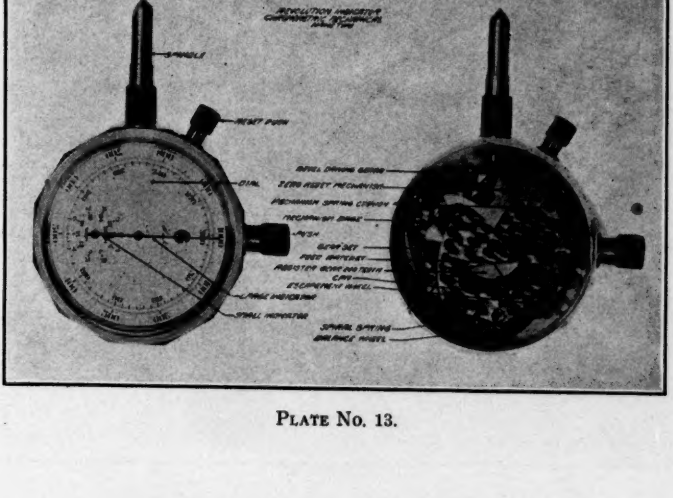


PLATE NO. 13.

PLATE NO. 15.

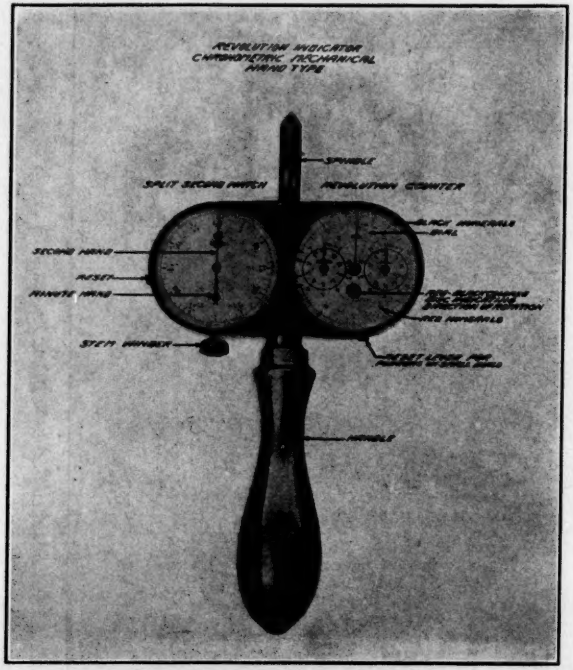


PLATE NO. 16.

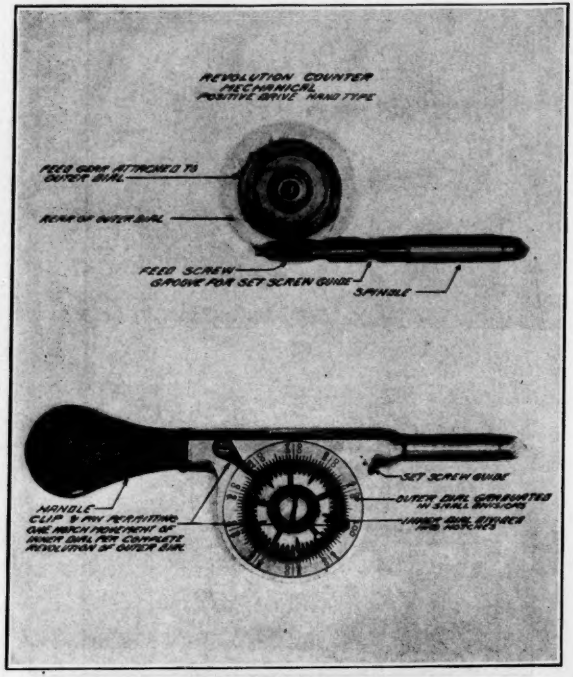


PLATE NO. 17.

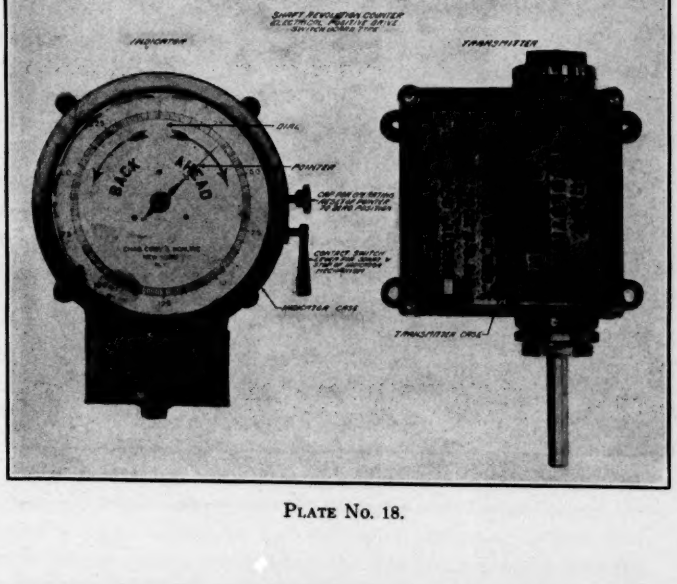


PLATE NO. 18.

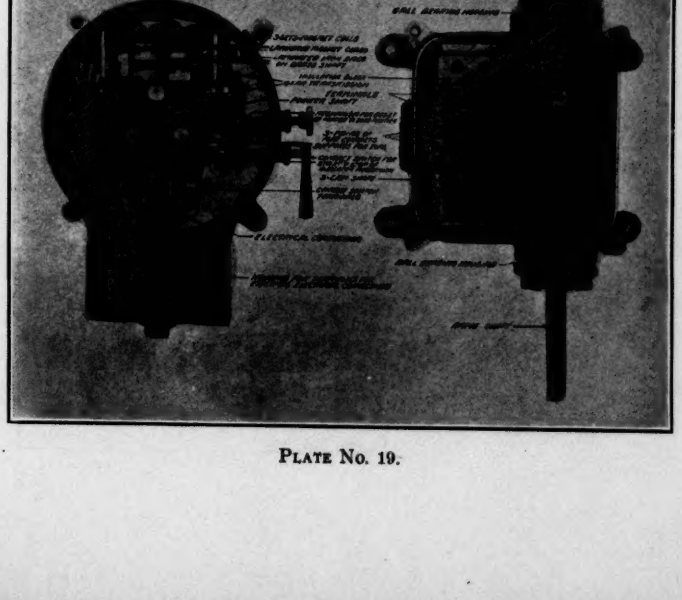


PLATE NO. 19.

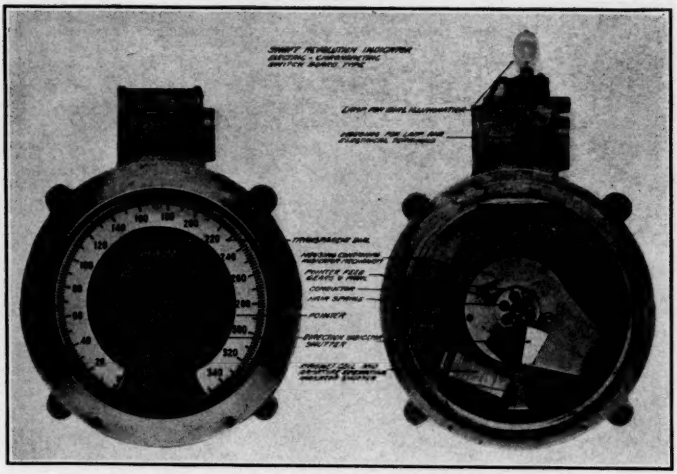


PLATE NO. 20.

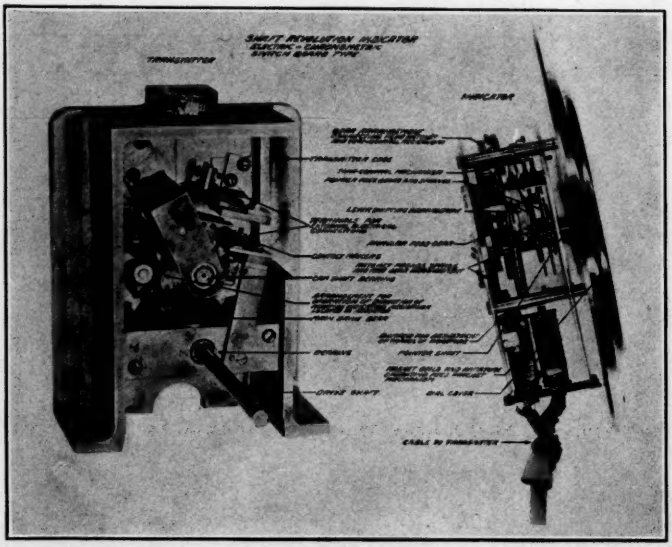


PLATE NO. 21.

device, which periodically controls the angular position of the indicating pointer and which in turn is geared to a ratchet-feed, oscillated by the drive shaft. Although this device appears somewhat intricate, the parts are fabricated equal in accuracy and fit to that of a chronometric clock, and the general reliability, ruggedness, repair and upkeep are of the same order. The chronometric device is automatically rewound during the indicating operation, and the starting and stopping errors of the timing device are eliminated in the design, in a similar manner to that described in the hand type mechanical, chronometric, revolution indicator, class 5a. The indicator registers the Average Revolutions Per Minute of the engine shaft, over a period of about 3 seconds. When indicating a steady engine speed the pointer remains stationary at the indication, but on varying engine speeds the pointer feeds notch by notch, until it indicates the average speed resulting from the three second interval, timed by the chronometric escapement. When the engine slows down to a dead stop the action of the indicator is to follow the retardation by indicating at intervals, until the zero mark is reached. At this point the chronometric device continues to function for 5 to 10 seconds, until the tension of the driving spring is exhausted. Upon starting, this spring is re-wound automatically, after which the escapement again controls the advance of the ratchet feed mechanism.

ADVANTAGES.

1. Mechanism is entirely mechanical, thereby eliminating all electrical generation or transmission requirements.
2. Requires very little driving torque.
3. Is not affected by magnetic stray fields.
4. Is applicable to all ranges of speeds.
5. Continuously indicates average revolutions per minute.
6. Mechanical wear of parts does not primarily affect accuracy of calibrations.
7. Has uniform scale graduations.

DISADVANTAGES.

1. It will not indicate instantaneous rates of speeds, or peak speeds.
2. It will not indicate fluctuating or pulsating speed changes.

3. Indicator records only one direction, although it operates from rotation in either direction.

4. Repairs or adjustments can readily be made only by the manufacturer of the instrument.

5. Indicator location is limited by practical limitations of extension shaft drive.

APPLICATION.

The mechanical chronometric revolution indicator of the switchboard type, is chiefly for installation such as on aeroplanes, where maintained accuracy is desirable, where the indicator can be installed in close proximity to the engine, where indications of accelerations or de-accelerations are not essential, and where compactness and readable indications of operating speeds are required.

CLASS 5(C).—REVOLUTION INDICATOR, CHRONOMETRIC, MECHANICAL, HAND TYPE.

The combination stop watch and counter type of hand operated revolution indicator, known as the tachoscope, is illustrated in Plate No. 16. This device combines a re-set type of mechanical revolution counter, and a stop watch, assembled in one portable unit for general test purposes.

EXPLANATION.

The operating principle of this device is that of a geared mechanical revolution counter unit, propelled from an extension spindle, in combination with a stop watch, mechanically connected to start when the spindle is depressed. Before the start of the reading both units are re-set to zero by the operator, by means of individual re-set levers. When readings are desired the device is inserted in the revolving center of the shaft under test, and depressed for a period of time, or until the large hand of the stop watch makes one revolution. At this instant the device is removed quickly from contact with the revolving shaft. The counter dial then registers the speed in revolutions per minute if operated for one minute, or the proportional rate if held for more, or less, than one minute.

ADVANTAGES.

1. Combines both mechanical counter and stop watch in one convenient unit.
2. Automatically starts the counter and stop watch at the same instant.
3. Applicable to all ranges of speeds in either direction of rotation.
4. Requires little driving torque.
5. Mechanical wear of parts does not primarily affect the accuracy of calibration.
6. Is not affected by external conditions.

DISADVANTAGES.

1. Size and general shape is not favorable for general test work.
2. Stop watch requires periodical winding.
3. Accuracy of stop watch employed is somewhat affected by the degree of winding or unwinding of drive spring.
4. To obtain readings for a definite period of time requires that the face of the watch be visible during the reading, therefore it is not suitable for all applications.
5. It will not indicate changes in rates of speed.
6. Appreciable interval of time is required to obtain practicable speed reading.

APPLICATION.

The combination stop watch and counter type of mechanical revolution indicator is primarily for use in general test purposes, where the average rate of speed for one minute is representative of the shaft speed under test. Due to the superior advantages of the hand type chronometric mechanical type in compactness, automatic features, general accuracy and quicker results, the combination type has been generally discarded.

CLASS 6.—REVOLUTION COUNTER, MECHANICAL, POSITIVE DRIVE, HAND TYPE.

Probably the simplest and best known device for obtaining the speed of accessible rotating shafts, is the mechanical hand-type revolution counter, illustrated in Plate No. 17. This device is

inexpensive, and in combination with the ordinary chronometer or stop watch, the R.P.M. of installed machinery or machines under test may readily be obtained with sufficient reliability to keep this device as a working standard wherever its limitations will permit.

EXPLANATION.

The operating principle is merely that of a rotating dial, graduated in 100 equal divisions, geared 1 to 100 ratio of the spindle, which in turn is held by hand in driving contact with the center of the shaft whose revolutions are to be counted. The scale-plate is usually driven from the geared spindle through a fiber friction disc so that the dial may readily be rotated to the zero mark for the start of the counting, and also so that, if desired, the spindle can be engaged with the shaft while the dial is held stationary, with the aid of the operator's thumb, and then be released at the start of the timing. One optional starting method, which prevents wear of the friction plate, is to set the dial to zero mark, and then apply the spindle at the same instant the stop watch is snapped, or at the instant the second hand of a chronometer passed its zero mark. Another optional starting method is to set the counter back of zero mark one or two notches, apply the counter to the shaft and snap the stop watch as both zero marks of the counter pass the spring clip. For each revolution of the spindle the outer dial advances one graduation, as indicated by its movement past a fixed mark. At every 100 revolutions the inner dial, which is a friction fit on the outer dial, and which is held from turning by a spring pointer, except when a projection on the outer dial raises the spring clip, advances on graduation, and thereby registers in units of one hundred. If the number of revolutions are counted for a period of one minute, the reading on the dial, when the counter is quickly withdrawn, then indicates direct in terms of the Revolutions Per Minute of the shaft. For rough checking the elapsed time can be reduced to ½ minute, or 10 seconds, the resulting count being then multiplied by 2 or 6 to obtain R.P.M. Accurate counting is limited chiefly by the starting and stopping errors. These errors are reduced as the interval of time is increased. However, these factors are offset by the assumption

that shaft under test may vary in rate of speed, if the reading is unduly prolonged. As a compromise for all conditions a one minute reading is the usual accepted practice.

ADVANTAGES.

1. Low cost, compactness and reliability.
2. Accuracy and reliability is not affected by external forces.
3. Accuracy is not affected by normal wear of parts.
4. Operates at all practical speeds.

DISADVANTAGES.

1. Cannot be used to indicate changing rates of speed, acceleration or de-acceleration of shafts.
2. Cannot be used to count or indicate speed of inaccessible shafts.
3. Cannot be used to indicate instantaneous rates of speeds.
4. Appreciable interval of time is required to obtain accurate count or rate of speed.
5. Reliability of method depends on the reliability of the stop watch used.

APPLICATION.

The hand type mechanical revolution counter is primarily used for test purposes where the shaft is readily accessible, for determining, in conjunction with a timing device, the average rate or settled speeds, of machinery installed, or under test.

CLASS 7.—REVOLUTION COUNTER, ELECTRICAL, POSITIVE DRIVE, SWITCHBOARD TYPE.

The electrical revolution counter of the fixed or switchboard type, as used in Naval Service, is illustrated by Plates No. 18 and No. 19. This device, consisting of a transmitter geared or belted to the propeller shaft, and a revolution counter indicator, is used for accurately counting the revolutions of the shaft at a remote location. In order to obtain the results in revolutions per minute it is necessary to employ a stop watch so that the indicator, when operated for a period of one minute, will register in terms of revolutions per minute.

EXPLANATION.

The transmitter consists merely of three cams, staggered 120 degrees from one another, mounted on the driven shaft. These cams, moving in sequence, operate contacts which are in series with a corresponding electro-magnet in the indicator. The source of energizing current is taken from the plant voltage normally 120 volts direct current. In the indicator three soft iron armature discs are mounted 120 degrees apart on a brass shaft adjacent to the three electro-magnets. As each electro-magnet is energized in sequence the corresponding armature is in a favorable position to rotate, by virtue of the principle that an iron armature free to turn will move so that the path of magnetic flux is the shortest. When this position is obtained the current is interrupted by the contact maker, and the energy is transferred to the next electro-magnet whose armature has been rotated by the common shaft, to bring the armature in position for further rotation. For reversed rotation no reversing gears are required, as the action of the electro-magnets on the rotating armatures is such that on reversed sequence of energizing current the rotation of the indicator shaft is accomplished in a reversed direction similar to the action in the forward direction. The movement of the magnetically rotated shaft of the indicator is transmitted by a gear system to the indicating pointer, which continues to rotate and count, in terms of the number of revolutions of the main shaft to which the transmitter is geared. An electrical starting switch and a mechanical re-set lever is incorporated in the indicator, so that the counting of the revolutions may be performed at will by the operator.

ADVANTAGES.

1. Distant operation is accomplished by electrical means, thereby eliminating mechanical shafting.
2. Accuracy and reliability is not affected by external conditions.
3. Accuracy is not affected by normal wear of parts.
4. Operates at all practical speeds, in either direction of rotation.
5. Is not affected by normal variation in energizing line voltage.
6. Permanent magnets are not employed in any part of the mechanism.

7. Has uniform scale graduation.
8. Has general ruggedness and simplicity of parts.

DISADVANTAGES.

1. Will not indicate instantaneous rates of speed, or speed changes.
2. Requires the use of a chronometer or stop watch to obtain revolutions per minute.
3. Does not automatically register the Revolutions Per Minute or Rate of speed.
4. Inductive arcing at the interrupting contacts of the transmitter is difficult to control at all speeds.

APPLICATION.

The electrical revolution counter, of the fixed switchboard type, is generally used for accurately obtaining the steady running speed of propeller shafts, where distant operation is required, where instantaneous rates are not required, and where the delay caused by timing with the aid of a chronometer or stop watch is not undesirable.

CLASS 8.—REVOLUTION INDICATOR, CHRONOMETRIC, ELECTRICAL, SWITCHBOARD TYPE.

The electrical chronometric revolution indicator, of the averaging, continuously indicating, switchboard or fixed type, is shown in Plates No. 20 and No. 21, which illustrate a recent development for indicating propeller shaft speeds. This system consists of a transmitter unit, geared or belt driven at a designed speed ratio from the shaft to be indicated, and one or more electrically operated, chronometric controlled indicators, mounted at a distance from the transmitter.

EXPLANATION.

The operating principle of the indicator is similar to that described as the chronometric-mechanical, switchboard type, revolution indicator class 5(b), except that the feed ratchet is operated by the magnetic pull of a direct current electro-magnet, periodically energized by power plant voltage. The periodical current related

to the shaft speed is obtained at a definite number of interruptions per minute from the transmitter, which is merely a mechanical contact-maker, driven by a cam on the transmitter shaft and wired in series with the electro-magnet of the indicator. The accuracy of the indication is not dependent on the value of the applied voltage, as variation in voltage merely changes the magnetic pull of the armature of the feed ratchet, but does not affect the number of transmitted interruptions per minute, on which the accuracy actually depends. As the indicator is calibrated and operates in only one direction, reversed rotation of the propeller shaft is indicated by a movable, visible shutter, attached to the armature of an electro-magnet, which is energized from the line voltage by reverse gear-driven contacts in the transmitter.

ADVANTAGES.

1. Mechanism is electrically operated, thereby permitting distant and multiple indicators.
2. Transmitter requires very little driving torque.
3. Not affected by temperature or magnetic stray fields.
4. Applicable to wide range of speeds.
5. Continuously indicates Average revolution per minute.
6. Mechanical wear of parts does not primarily affect accuracy of calibration.
7. Employs no permanent magnets.
8. Uniform scale graduations.
9. Not affected by contact or line resistance changes, or voltage variations.

DISADVANTAGES.

1. Will not indicate instantaneous rates of speed or peak speeds.
2. Will not indicate fluctuating or pulsating speed changes.
3. Repairs or adjustments on indicator can readily be made only by the manufacturer of instrument.
4. Inductive arcing at the interrupting contacts of the transmitter is difficult to control at all speeds.
5. Indicator mechanism requires accurate and closely fitted parts.

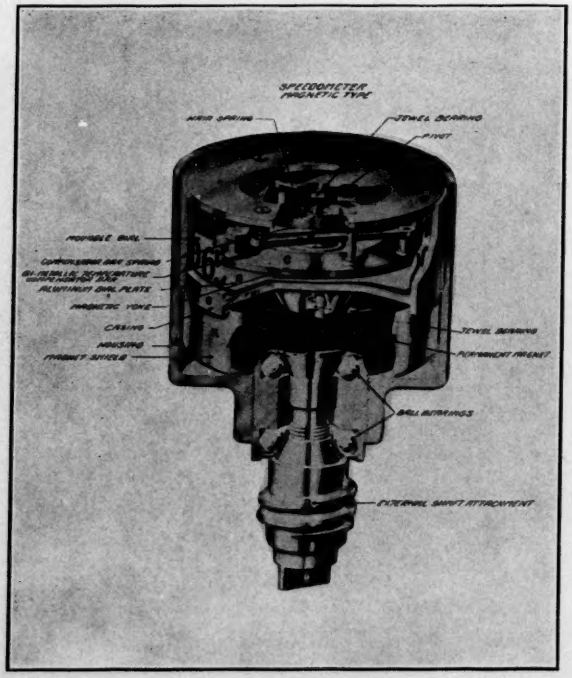


PLATE NO. 22.

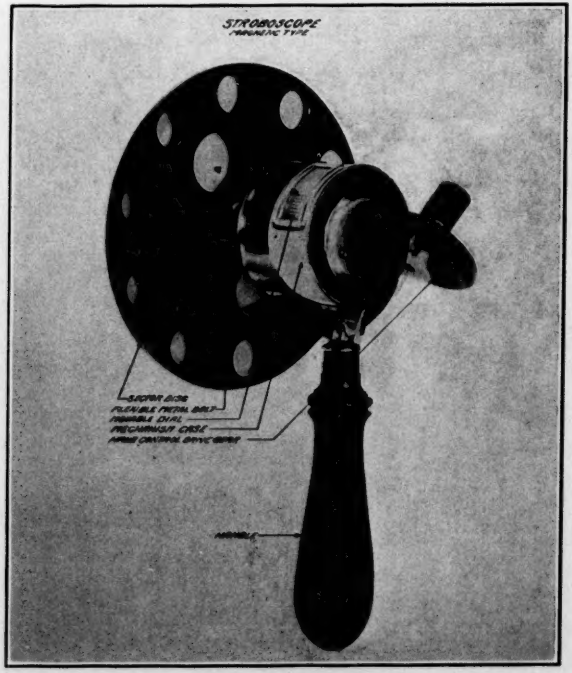


PLATE NO. 23.

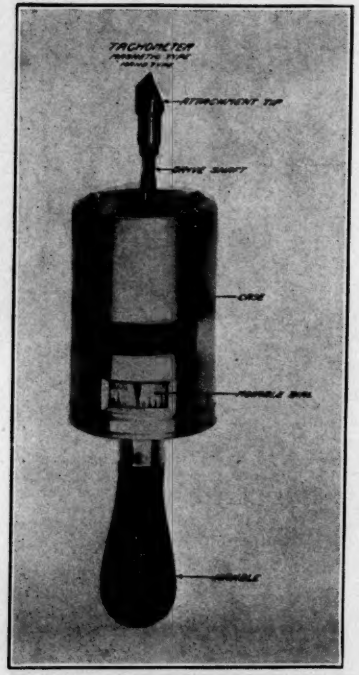


PLATE NO. 24.

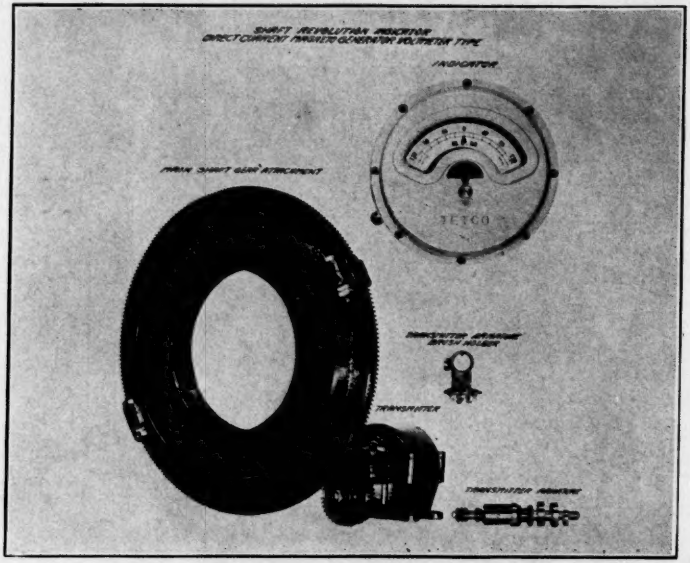


PLATE NO. 26.

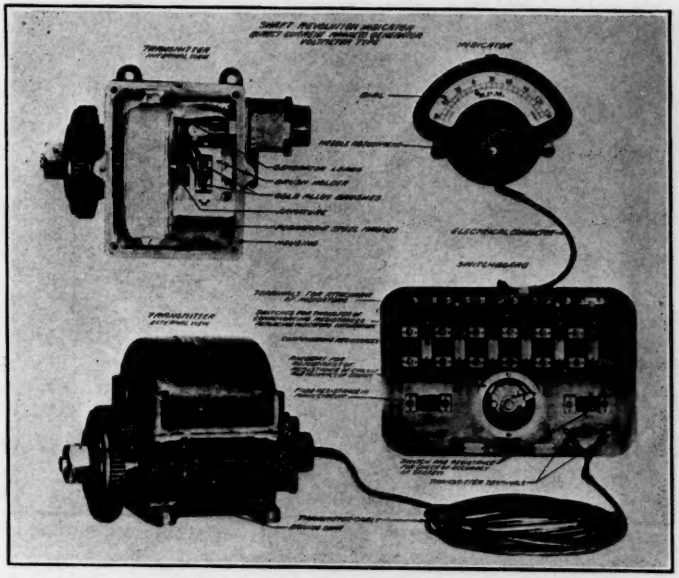


PLATE NO. 27.

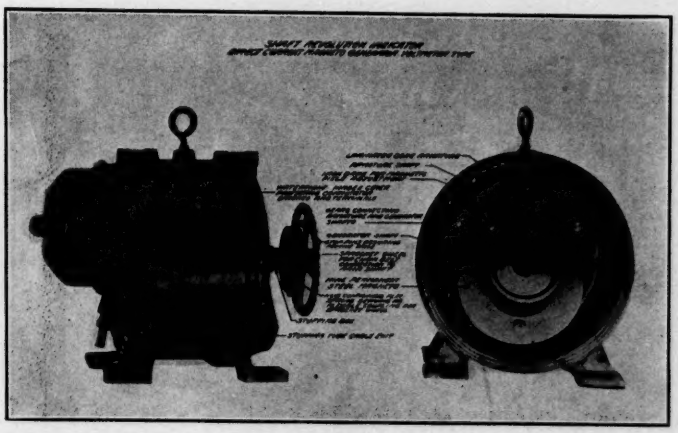


PLATE NO. 28.

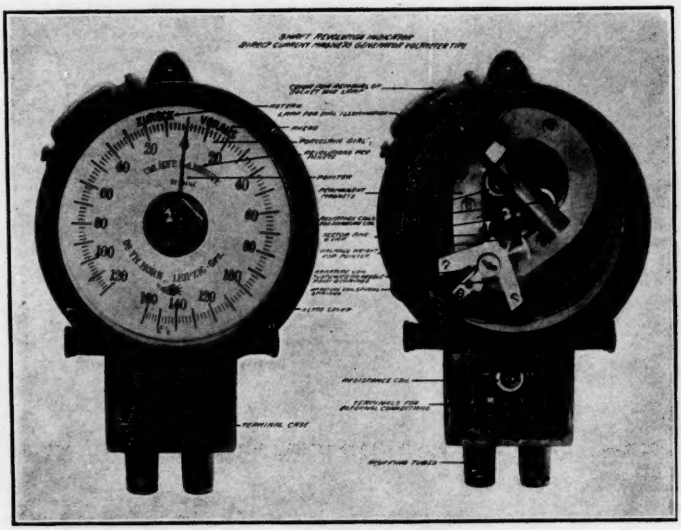


PLATE No. 29.

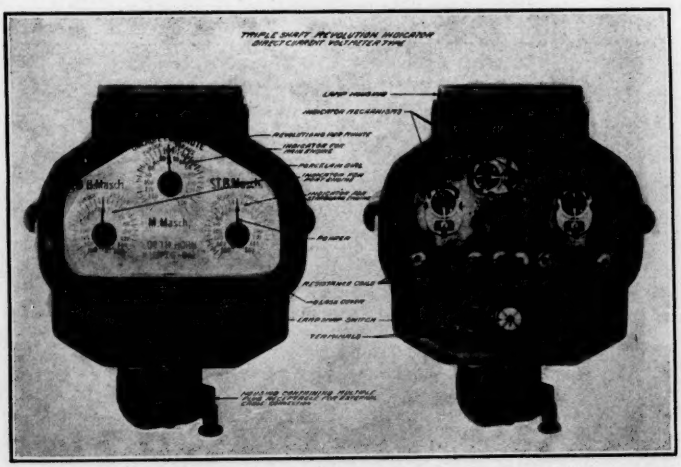


PLATE No. 30.

APPLICATION.

The electrical chronometric revolution indicator when perfected is suitable for installations where indications of accelerations or de-accelerations are not essential, where maintained accuracy is required and where distant and readable indications of operating speeds in either direction are desired.

CLASS 9.—MAGNETIC SPEEDOMETERS AND TACHOMETERS.

This group of indicators, for use on fixed installations as Speed indicators or as portable Tachometers, has a wide range of application, for the reason that the indicator contains all the elements for the reception and indication of the speed of the machine to be indicated. This type of instrument, illustrated by Plate No. 22, is in common use in automobiles, which, when gear driven through a flexible metallic shaft, registers the speed in miles per hour. It is applied in the same manner to obtain the R. P. M. of aeroplane or motor-boat engines. In portable form it is used for general test purposes for obtaining the approximate speed of any revolving shafts, or as a portable stroboscope, to obtain the speed of revolving fans, gyro compass rotors or other revolving parts, where mechanical contact is impracticable.

EXPLANATION.

The operating principle of the magnetic type is explained as follows, referring to Plate No. 22. A permanent magnet of circular form is keyed to the driving mechanism of the indicator. Adjacent and concentric with it is a hollow aluminum cup mounted on jeweled bearings. The outside surface of the cup is graduated in R.P.M. in the tachometer or stroboscope, or in miles per hour in the speedometer. The revolving permanent magnet sets up eddy currents in the material of the cup, which in turn tends to revolve with the magnet by virtue of magnetic drag action, similar in principle to the revolving disc of watthour meters. The rotation of the cup is opposed by spiral control springs, the resultant of the two forces being calibrated in terms of the application. As the temperature coefficient of the aluminum disc is appreciable, mechanical compensation of the control springs is provided to

offset the effect of temperature on the generated eddy current in the cup. On the stroboscope, illustrated in Plate No. 23, the mechanism, including a sectored external disc, is operated by a hand-driven gear, at a shaft speed at which the light wave interference, sighted through the holes in the disc, balances the speed of the moving machine whose speed is desired. Normally, the indicator is designed for one direction speed and one direction indications. The hand type tachometer illustrated in Plate No. 24 is equipped with a uni-direction gear drive, which serves for clock-wise or counter clock-wise shaft rotations, indicating on a one way scale.

ADVANTAGES.

1. Compactness and reliability of mechanism.
2. Mechanical compensation for temperature effect.
3. Requires lubrication only on the drive shaft bearings.
4. Uniformity of scale graduations.
5. The circular form of scale, results in unusual scale length compared with size and weight of indicator.
6. The lightness in weight of the moving element results in reliability.

DISADVANTAGES.

1. Permanency of calibration is affected by deterioration of the strength of the permanent magnet.
2. The torque of the indicating mechanism is of low order, and accuracy is affected by slight changes in control spring strength and bearing friction.
3. Accuracy is affected by close proximity to large masses of iron or steel which reduces the effective strength of the permanent magnet.
4. Indicator reads normally only one direction of speed.
5. The operation on quick changes or fluctuations of speeds is unsatisfactory, due to the low order of the dampening and torque factors in the indicator.

APPLICATION.

The use of the magnetic type speedometer is confined to applications where accuracy is not an essential function of operation,

where the indicator can be installed in close proximity to the prime mover, where indications of acceleration or de-acceleration are not essential, and where readable indications are desired from zero to maximum speeds.

CLASS 10(A).—DIRECT CURRENT MAGNETO GENERATOR TACHOMETERS AND REVOLUTION INDICATORS.

The diagrammatic scheme of the direct current magneto-generator type is illustrated in Figure No. 25. This system has

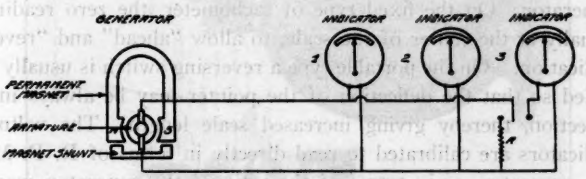


FIG. 25

DIRECT CURRENT, MAGNETO-GENERATOR VOLTMETER TYPE, REVOLUTION INDICATORS — PARALLEL SYSTEM

been widely used for indicating shaft revolution per minute and appears in more forms and makes than any other system. Plate No. 26 shows a watertight indicator with the generator geared to a propeller shaft. Plate No. 27 shows a non-watertight indicator with compensator control board and generator. Plates Nos. 28 and 29 show a foreign make generator and indicator with extra large permanent magnets and dial. Plate No. 30 shows a triple indicator in one housing, which indicates the speeds of three propellers. Plate No. 31 shows the generator and indicator combined in one unit for use as a portable Tachometer.

EXPLANATION.

The generator is of the so-called magneto type for the reason that it is excited by means of a permanent magnet. The armature is wound to give the desired ampères and volts, when rotated in the air gap flux of the magnet poles. In the fixed type the armature is driven from the shaft, whose speed is to be indicated, by means of a chain, belt or gear, the ratio of drive of which is such

as to co-ordinate the armature speed with the scale markings on the indicator. On the hand type the armature is driven direct from the shaft whose speed is desired, by means of an extension tip on the armature shaft, applied by the operator to the revolving shaft center.

Carbon or metal brushes are used to commutate direct current voltage, which is practically proportional to the speed within the working range of the system. The indicating instrument used may be one of the direct current voltmeter types, of suitable range to correspond with the designed voltage of the magneto-generator. On the fixed type of tachometer, the zero reading is usually at the center of the scale, to allow "ahead" and "reverse" indication. On the portable type a reversing switch is usually provided so that the deflection of the pointer may be always in one direction, thereby giving increased scale length. The voltmeter indicators are calibrated to read directly in terms of R. P. M. of the generator, or in terms of the ratio of the generator speed to the gear, belt or chain speed, from which the indicator is coordinated with the shaft to be indicated. The magneto-generator is usually equipped with a soft iron adjustable shunt, placed across the poles of the magnet, in order that the generated voltage may be adjusted to the desired amount, and also, to permit adjustment for loss in strength of the permanent magnet due to aging. When only one indicator is required on the system, the generator needs have only sufficient ampère capacity to operate the indicator. When two or more indicators are required to operate in parallel from one generator, two general schemes are used to compensate for the decrease in volts caused by the I^2R loss in the generator armature. One scheme, which is perhaps the simplest, is to use a generator of excess current capacity, so that the I^2R change in voltage will be negligible when additional indicators are cut in or out of the system. The other scheme is to employ an external compensating resistance with each indicator, and operated by a hand cutout switch, so that the total ohms resistance of the external circuit will always be the same, as illustrated in Figure 25, indicator 3. This latter system permits the use of a smaller capacity generator.

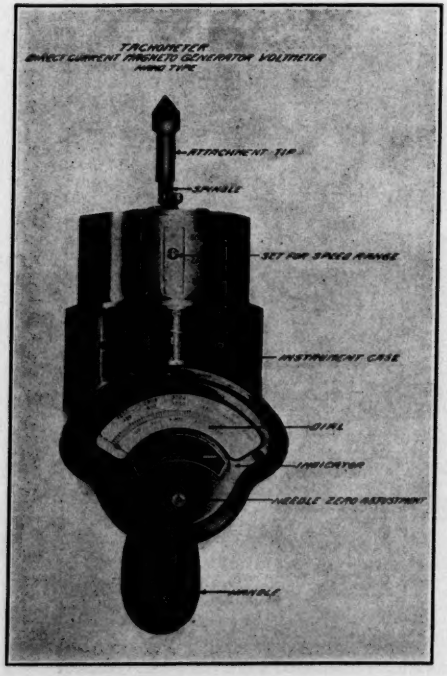


PLATE NO. 31.

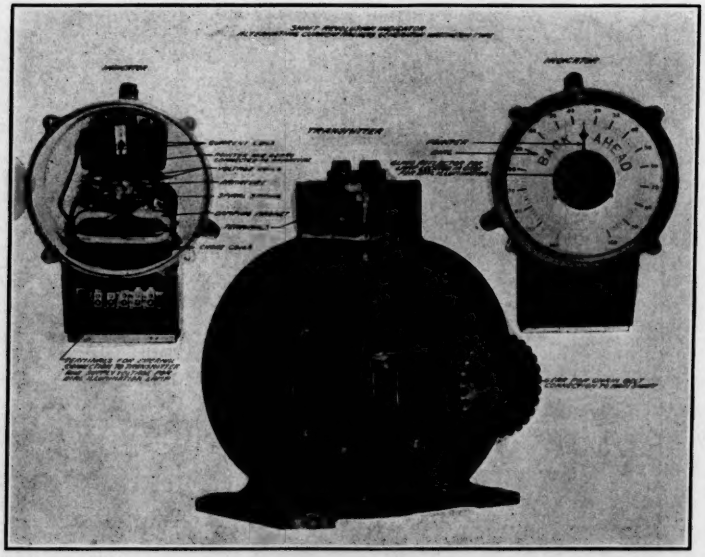


PLATE NO. 33.

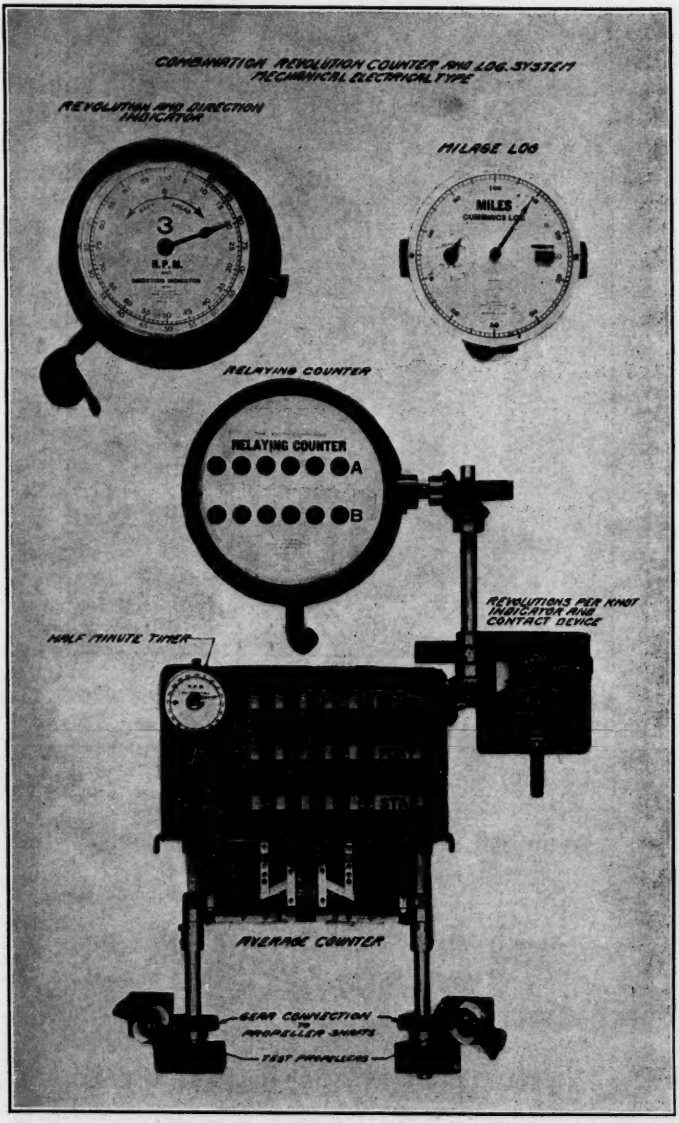

COMBINATION REVOLUTION COUNTER AND LOG SYSTEM
MECHANICAL ELECTRICAL TYPE
REVOLUTION AND DIRECTION INDICATOR
R.P.M.
MILAGE LOG
MILES
RELAYING COUNTER
RELAYING COUNTER
A
B
REVOLUTIONS PER KNOT INDICATOR AND CONTACT DEVICE
HALF MINUTE TIMER
AVERAGE COUNTER
GEAR CONNECTION TO PROPELLER SHAFTS
TEST PROPELLERS

PLATE NO. 34.

Another multiple system which incorporates a number of interesting features, is one in which the indicators are all in series, and for a four shaft ship a generator is provided for, and is driven by each of the four shafts. In this system the two Starboard shaft generators and the two Port shaft generators are wired in series through two groups of indicators located in the various stations of the ship. One of these groups, being wired in series with two generators, are thus designed to read the *average* R.P.M. of

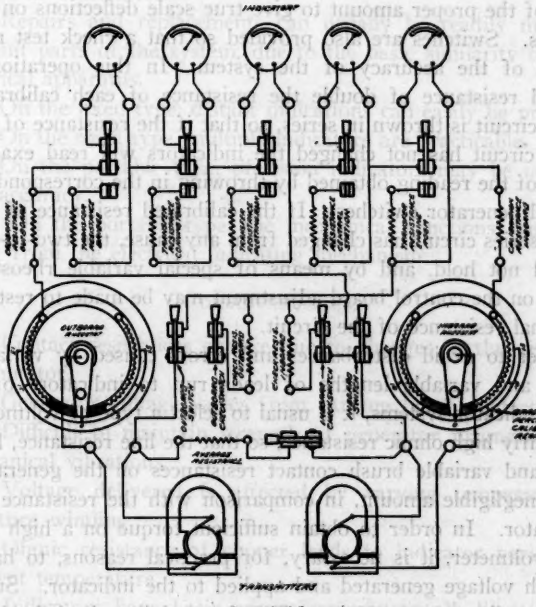


FIG 25 A

DIRECT CURRENT MAGNETO-GENERATOR VOLTMETER TYPE REVOLUTION INDICATORS, SERIES TYPE.

the two Starboard shafts, and the other group indicates the *average* R.P.M. of the two Port shafts. As shown in Figure 25A, a master control board is supplied for the Port shafts, and a reverse duplicate, not shown, is provided for the Starboard switches for disconnecting each of the individual indicators, and

also to substitute for the indicators and their feed lines, equivalent fixed resistances. Thus, if any one of the indicators or their supply lines become open or short circuited it may be switched out of the series circuit, and the accuracy of the remaining indicators will be maintained. Switches are provided also so that the indicators may be connected to and read the R.P.M. of either of the two shafts, in place of the average R.P.M. In this operation a fixed line resistance equal to the ohmic resistance of all indicators plus their lines, is shorted out, so that the one generator supplies voltage of the proper amount to give true scale deflections on the indicators. Switches are also provided so that a check test may be made of the accuracy of the system. In this operation a calibrated resistance of double the resistance of each calibrated working circuit is thrown in series, so that if the resistance of the working circuit has not changed the indicators will read exactly one-half of the reading obtained by throwing in the corresponding individual generator switches. If the calibrated resistance of the working series circuit has changed from any cause, the two-to-one ratio will not hold, and by means of special variable rheostats provided on the control board adjustment may be made to restore the original resistance of the circuit.

In order to avoid disturbances and errors caused by variable contacts, and variable lengths of leads run to indicators of a multiple indicator systems, it is usual to select a type of voltmeter having fairly high ohmic resistance, so that the line resistance, line contacts and variable brush contact resistances on the generator are of a negligible amount, in comparison with the resistance of the indicator. In order to obtain sufficient torque on a high resistance voltmeter, it is necessary, for practical reasons, to have fairly high voltage generated and applied to the indicator. Such systems usually operate at about 60 volts at full scale deflection. Some systems, however, operate on as low as 6 volts in order to avoid commutation and brush troubles. In such systems, in order to reduce the brush contact loss to a minimum and to produce unvarying voltage, it becomes necessary to use metal brushes and a commutator of slow oxidizing properties, such as a gold alloy. The indicating instruments in such systems are of correspondingly low ohmic resistance, and suitable compensation must be made for unequal length of leads on multiple indicator systems.

ADVANTAGES.

1. Commercial designs of direct current voltmeter may be used as the indicators.
2. Uniform scale markings from zero to maximum.
3. Wide range of speeds in either direction.
4. Adjustments for accuracy are practical.
5. Indications may be designed to closely follow the accelerations and de-accelerations of normal shaft speeds, a necessary feature in Tachometers.
6. Repairs and replacements can usually be readily made on the unit parts of the system, due to the basic similarity to other electrical apparatus.
7. On the fixed type, distant indications can easily be provided.
8. On the fixed type, multiple indicators are practicable.
9. On the portable type, precision indicators may be used for high accuracy.
10. On the portable type, the mechanical functions are segregated from the electrical indicating mechanism.

DISADVANTAGES.

1. Contact resistances change due to changes in the generator commutator.
2. Generator voltage varies from varying brush contact.
3. Difficult to maintain strength of generator magnets due to mechanical vibrations.
4. Voltage delivered is affected by varying temperature of armature winding.
5. Ohmic resistance of copper leads to indicator varies with ambient temperature.
6. Indicators have basic errors common to all direct current voltmeters, due to temperature, stray magnetic fields, loss in strength of permanent magnets, friction of moving coil system, vibration, changes in control springs, torque, etc.

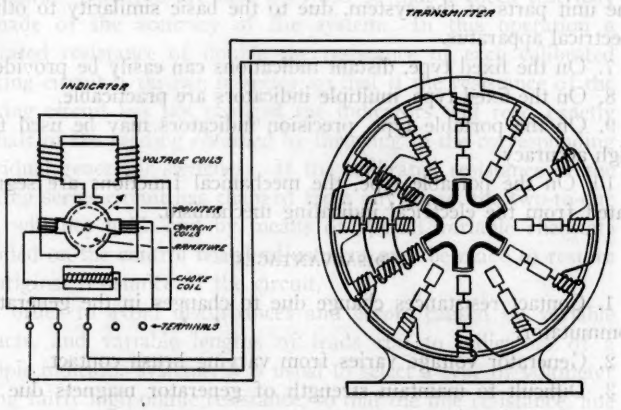
APPLICATION.

The direct current form of magneto-generator revolution indicator, is used on fixed installations, to indicate the operating speeds

of shafts, where maintained accuracy is not essential, and where distant or multiple indicators are required at low installation cost. For portable, or test purposes, the application is becoming obsolete due to the greater advantages of the centrifugal and chronometric types.

CLASS 10(B). ALTERNATING CURRENT MAGNETO-GENERATOR WATTMETER TYPE REVOLUTION INDICATOR.

The diagrammatic scheme of the alternating current magneto-generator, induction wattmeter type, revolution indicator, is shown



A TRIPLE CIRCUIT TRANSMITTER SHOWING WIRING FOR ONE INDICATOR

FIG. 32

REVOLUTION INDICATOR
ALTERNATING CURRENT MAGNETO GENERATOR WATTMETER TYPE

in Figure 32. Plate No. 33 shows the application to a propeller-shaft revolution indicator of the type which has been used to some extent in Naval service.

EXPLANATION.

The generator is of the so-called Magneto type, for the reason that it is self-excited by means of permanent magnets in the form of a multipolar rotor. This rotor is revolved by means of a chain drive from the propeller shaft in the air gap of a series of projecting stationary fixed poles, on which are wound alternately, a

Voltage and a Current generating winding. The poles of these two separate windings are electrically spaced, so that the currents generated by the revolving magnet poles are 90 degrees in phase difference. The wattage power delivered by the generator, in combination with the adjustments of the indicator, is regulated to be directly proportional to the speed of the generator. The dial of the indicator is calibrated in equivalent revolutions per minute of the propeller shaft. The indicator is of the single phase alternating current wattmeter type, operating on the induction principle, practically similar to the commercial types with one major exception. In the commercial meter, the torque of the moving element, which is a hollow aluminum cup, is produced by the magnetic drag of a rotating field set up by the current and voltage windings on the core at 90 degrees displacement, when indicating the watts input at 100 per cent power factor. This phase displacement is obtained by the design of the Instrument. In the revolution indicator system, the necessary phase displacement is obtained in the design of the Generator, thereby simplifying the construction of the indicator by virtue of the Generated phase relation. Separate windings are employed on the generator for the operation of multiple indicators, and the connection is made to each indicator by means of three leads, one of which is common to the generated two-phase currents. By employing a geared-up, indicating hand, on the indicator, the graduations of the dial extend over a large arc between full range "ahead," to full range "astern."

ADVANTAGES.

1. Commutator or brushes are not employed in the design of the generator.
2. By employing multiple circuits on the generator, the indications of one indicator are not affected by the placing of other indicators on a multiple indicator installation.
3. No revolving windings on generator.
4. Well defined scale markings on indicators at all speeds.
5. Indications closely follow changes in shaft speeds.
6. Suitable for remote indication.
7. Multiple indicators may be employed.

DISADVANTAGES.

1. Calibration affected by deterioration of strength of permanent magnet employed in generator.

2. Calibration affected by changes in operating and ambient temperature caused by ohmic variations in the copper circuits.

3. Accuracy of indicators is affected by stray magnetic fields, vibration, and control spring variation in the moving element.

APPLICATION.

The alternating current, watt-meter-magneto-generator revolution indicator, is used chiefly for fixed installation on shipboard for indicating the propeller shaft speeds, where distant and multiple indicators with large readable scales are required for operations, and where maintained accuracy is secondary to other primary advantages of this system.

CLASS 11.—COMBINATION REVOLUTION COUNTER AND LOG SYSTEM, MECHANICAL, ELECTRICAL, FIXED TYPE.

The mechanical-electrical revolution counter and log system of the fixed type, for a two-shaft installation, is illustrated in Plate No. 34. This combination outfit is one of the recent developments designed for logging the total revolutions of two separate propeller shafts; for logging the total revolutions of the average of the two shafts; for indicating the direction of rotation; for logging the mileage of the ship based on shaft revolutions; and, in conjunction with a stop watch or chronometer, for obtaining the rate of speed or revolutions per minute, of either of the two shafts. The complete outfit is more or less expensive and elaborate, but contains all the basic elements for obtaining local and distant recording of the performance of the shafts, for the purpose of control and logging.

EXPLANATION.

The main unit of the system consists of two shaft-driven mechanical revolution counters, located in the engine room, and connected by gears and extension shafts, to the port and starboard

propeller shafts. The revolutions of these shafts are recorded by direct mechanical one-way drive on the corresponding rotating cyclometer mechanism which counts in single revolutions up to its numerical capacity, at which point it continues its cycle of counting, starting at zero. A third cyclometer member in the same unit is mechanically driven by a differential gear system, connected to the port and starboard counters, which by virtue of the differential action, records the average revolutions of the two shafts. A cross-shaft, driven by a two-to-one gear from the averaging counter, operates a rotating hand on a numbered dial which is used for obtaining the average revolutions per minute over an interval of a half minute, timed by the operator with the aid of a chronometer or stop watch. An extension shaft from the averaging counter is employed to mechanically operate an electrically hand-controlled relay cyclometer, installed at a distance, for obtaining duplicate recording of the revolutions. The extension shaft also operates a cam-driven contact-making device, which in turn, operates a distant mileage log of the electro-magnet-ratchet type, excited from the plant voltage. A mechanical controlling device is incorporated on this contact-maker, which, by means of a system of selected gears based on the speed curves of the ship, converts the Revolutions of the Averaging shaft in terms of Revolutions per Knot. This, in turn, is transmitted electrically to the mileage log indicator, and records total mileage on a cyclometer mechanism. Two additional electro-magnet-ratchet type indicators are provided, one for the port, and one for the starboard shaft. These instruments installed at a distance and energized from the plant voltage, indicate the Revolutions and Direction of rotation of the shafts by means of contact-makers geared to the individual shaft revolution counters on the main unit.

ADVANTAGES.

1. The primary mechanism is Direct Mechanical drive, which has inherent accuracy.

2. Wear of parts does not primarily affect the accuracy of indication.

3. Distant indications are provided by electrical transmissions, which are not affected by variation in voltage, line resistance, or by magnetic stray fields.

4. Various operating conditions are recorded and indicated in one combined outfit.

DISADVANTAGES.

1. Requires extensive use of gears, bearings, universal joints and connecting shafts. The mechanical failures may be expected, due to inherent friction, lack of lubrication, distortion of parts, or unavoidable damage during ship repairs.

2. Requires the use of a stop watch or chronometer and considerable time interval, to obtain the rate of speed or revolutions per minute.

3. Acceleration, de-acceleration or quick changes in speeds, cannot be determined.

APPLICATION.

The revolution counter and log system is primarily for use on shipboard where accurate recording of the total revolutions is required; where accurate average rate of steady running shaft speed is required; and where the assumed mileage of the ship, based on propeller revolutions, is required.

CLASS 12.—COMBINATION REVOLUTION INDICATOR AND LOG SYSTEM, ELECTRICAL-CHRONOMETRIC, FIXED TYPE.

The revolution indicator and log system of the electrical-chronometric, fixed type, is illustrated in Plates No. 35 and No. 36. This combination outfit is one of the recent developments for separately indicating the Revolutions per Minute of two propeller shafts; for indicating the Average revolutions per minute of two shafts in combination; for logging the Total Revolutions of the average of two shafts; and, for logging the Mileage of the Ship. This system is more or less expensive and elaborate, but contains all the basic elements for distant indicating, by electrical transmission, the performance of the shafts, for the purpose of control and logging.

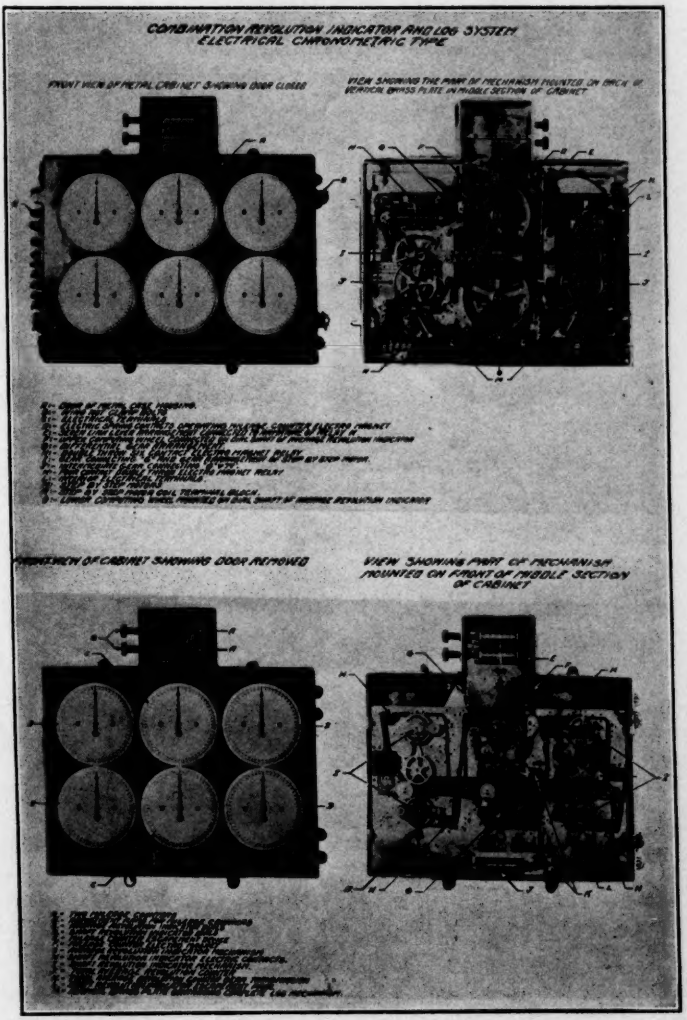

COMBINATION REVOLUTION INDICATOR AND LOG SYSTEM
ELECTRICAL CHRONOMETRIC TYPE
FRONT VIEW OF METAL CABINET SHOWING DOOR CLOSED
VIEW SHOWING THE PART OF MECHANISM MOUNTED ON BACK OF VERTICAL BRASS PLATE IN MIDDLE SECTION OF CABINET
VIEW SHOWING PART OF MECHANISM MOUNTED ON FRONT OF MIDDLE SECTION OF CABINET

PLATE NO. 35.

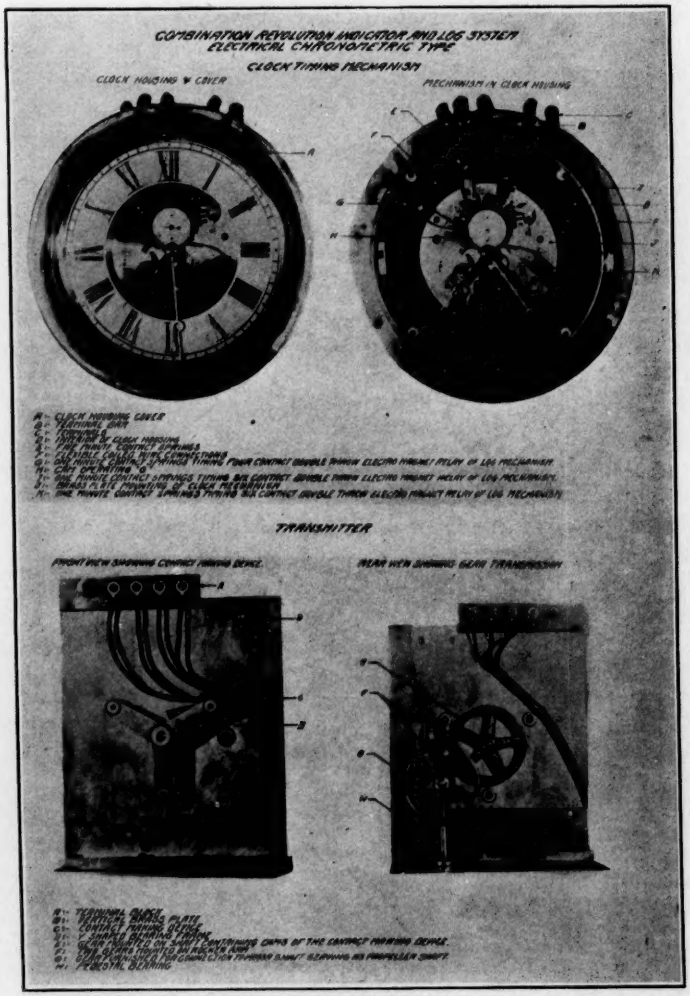

COMBINATION REVOLUTION INDICATOR AND LOG SYSTEM
ELECTRICAL CHRONOMETRIC TYPE
CLOCK TIMING MECHANISM
CLOCK HOUSING & COVER
MECHANISM IN CLOCK HOUSING
TRANSMITTER
FRONT VIEW SHOWING CONTACT MAKING DEVICE.
REAR VIEW SHOWING GEAR TRANSMISSION

PLATE NO. 36.

EXPLANATION.

The operating principle, in general, consists of two electrically operated revolution indicators, in Duplicate for Each shaft. These indicators are propelled by geared step-by-step motors, energized from a 20-volt direct current supply through the medium of a cam-driven contact maker which in turn is geared to a one-way drive to each propeller shaft. The control of the step-by-step motors is obtained through the medium of a chronometric, 8-day master clock, which by means of timing contacts, permits the motors of one of each duplicate indicator to rotate step-by-step in synchronism with the propeller shafts, for a period of one minute. These indicators then record in terms of the revolutions per minute of each shaft. After a rest of interval of 55 seconds, the indicator pointers return to zero markings for re-start, five seconds later. During the rest interval of each indicator, its Duplicate indicator is in process of counting off the revolutions for a period of one minute. The purpose of this cycle of operation is to always have one or the other of the duplicate indicators at rest, so that the speed of the shafts may be continuously visualized at any instant, except during an interval of five seconds when the indicating pointers are returning to the zero mark.

The Average revolutions per minute of the two propeller shafts in combination is obtained by Duplicate indicators, mechanically connected by differential gears to the separate shaft indicators, and controlled by the master clock mechanism to obtain the cycle of one minute counting, 55 seconds at rest, and 5 seconds for return to zero.

The Total Revolutions of the average of the two shafts is recorded by a continuously counting mechanism of the Veeder mechanical type, geared to the averaging indicators by a one-direction combination drive.

The Mileage log consists of a reset type Veeder mechanical counter, in duplicate, driven from the averaging indicator mechanism through the medium of geared computing wheels. These wheels are designed to give the correct ratio of drive, based on the speed curves of the ship, in terms of the Average shaft revolutions of the two shafts.

ADVANTAGES.

1. The transmitter being merely a contact maker, its performance does not primarily affect the accuracy of the system.

2. All extension shafts, universal joints and gears are eliminated between the transmitters and the indicators.

3. Wear of any mechanical part does not primarily affect the accuracy of indications.

4. Distance indications are provided by electrical transmission which are not affected by variation in voltage, line resistances or by magnetic stray fields.

5. The Basic accuracy is dependent on chronometric control which has inherent sustained accuracy.

6. Accuracy is not dependent on strength of permanent magnets, generated voltages or control springs, excluding the control springs in the chronometer.

7. Various operating conditions are recorded and indicated in one combined outfit.

DISADVANTAGES.

1. The mechanism of the indicator system is complicated, and to maintain continuous operation requires precision in workmanship and lubrication.

2. System contains numerous electrical make and break contacts which require a high degree of skill to properly design and maintain in operating condition.

3. Accelerations, de-accelerations or quick changes in speed cannot be determined.

APPLICATION.

The revolution indicator and log system is primarily for use on shipboard where maintained accurate recording of the steady running shaft speeds is required; where recording of the total revolutions is required; and where the assumed mileage of the ship, based on propeller revolutions, is required.

CLASS 13.—THE PULSATOR SPEED AND DIRECTION TELEGRAPH.

One of the newer speed indicator systems for distant control of ships' engines and propeller shafts, and allied applications, known

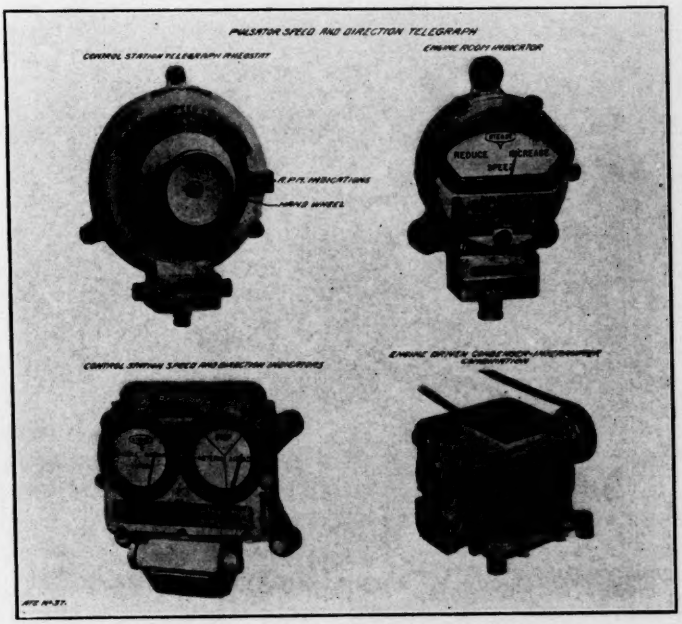

PULSATOR SPEED AND DIRECTION TELEGRAPH
CONTROL STATION TELEGRAPH RHEOSTAT
R.P.M. INDICATING
HAND WHEEL
ENGINE ROOM INDICATOR
REDUCE
INCREASE
SPEED
CONTROL STATION SPEED AND DIRECTION INDICATORS
ENGINE DRIVEN GENERATOR-UNDERMOUNT COMBINATION
APG No. 37.

PLATE NO. 37.

as the Pulsator Speed and Direction Telegraph, is illustrated in Plate 37. This system is of fundamental simplicity, as its inherent accuracy is dependent only on the variations in effective resistance of a revolving condenser, rotated by the shaft whose speed or direction is to be indicated. Figure 38 shows the appli-

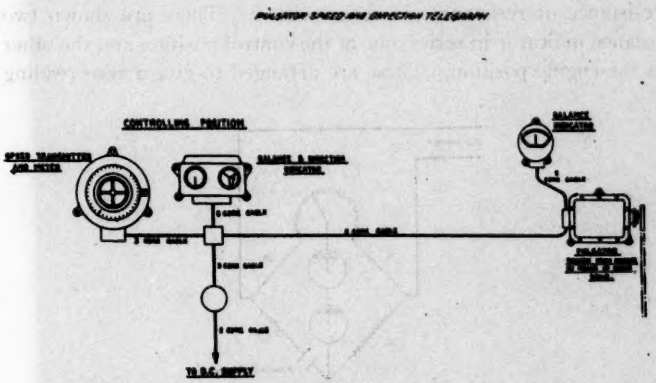


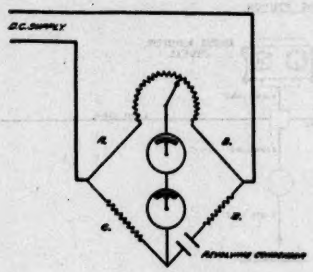
FIG. 38.

cation of this system to a single shaft ship, and by means of this arrangement, it serves as a telegraph system between the bridge and the engine room.

EXPLANATION.

This system depends for the constancy of its indications on the capacity of an electrical condenser, and on the value of an ordinary non-inductive resistance. The method of working is analogous in electrical principle to the operation of balancing a Wheatstone Bridge. The condenser used has a constant capacity which is independent of temperature variations. Figure 39 is a fundamental diagram showing the application of the Wheatstone Bridge. Figure 40 shows the application of the unit parts of the pulsator system, including the engine-driven pulsator, the indicators, the R.P.M. rheostat, and the direction of rotation device. By referring to Figure 40, it will be seen that two of the Wheat-

stone Bridge arms marked A and B in Figure 39 are at the Navigator's station. These arms consist merely of a rheostat divided by a movable contactor into parts of variable ratio to one another. This contactor carries a pointer which moves over a scale calibrated in R.P.M. The other side of the bridge comprises a condenser-interrupter combination, called the Pulsator, and a fixed resistance or resistances in series with it. There are shown two balance indicator in series, one at the control position and the other at the engine position. These are arranged to give a zero reading



when the engine or shaft is running at the speed shown on the dial of the rheostat speed meter. The condenser-interrupter combination acts exactly as an ordinary non-inductive resistance, and its apparent resistance in the circuit is inversely proportional to the speed at which the interrupter is driven. Its effective resistance is therefore altered as the speed alters, and a different point of electrical balance is required on the rheostat for each speed of the engine shaft.

By means of this system, the operator at the control station can set the rheostat to the speed desired and both the engine man and operator can determine by the calibrated deflection of their indicators the amount the speed needs to be raised or lowered. When this is accomplished, both indicators will read zero deflection, and both stations will readily know that the order has been carried out. Again, if the order has not been carried out, the control station may shift the rheostat until balance on the indicator is obtained, at

which point the actual R.P.M. will be indicated on the rheostat pointer.

The direction indicating scheme, shown diagrammatically in Figure 40, consists of a polarized moving coil instrument at the control position, suitably marked "Ahead," "Stop," and "Astern," connected through a change-over switch across one of the resistances in series with the condenser-interrupter combination. The change-over switch is operated by means of a friction clutch, and is moved into and remains in one of two positions,

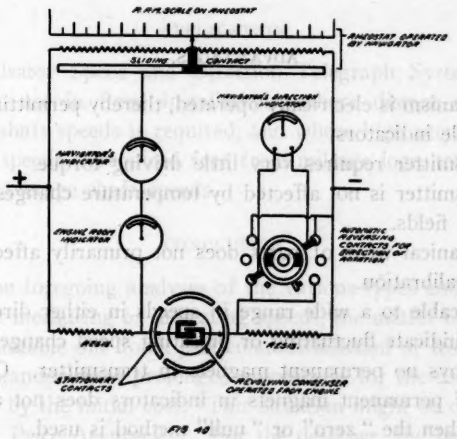


FIG 40

PULSATOR SPEED AND DIRECTION TELEGRAPH.

depending on the direction of rotation of the engine. If the switch is in, say "Ahead" position, the indicator will show "Ahead" so long as the engine is turning, because the engine in so doing causes a current to flow through the resistance in series with the condenser-interrupter combination. The potential thus formed from this resistance causes an exciting current to flow in a definite direction, to the polarized moving coil of the direction indicator. But as soon as the engine stops, the condenser becomes fully charged in one direction and no further current can then flow through the resistance across which the direction indicator is con-

nected. The pointer of the indicator will therefore go to " Stop" and remain there no matter where the change-over switch may be, so long as the engine is stationary. When the engine revolves in the opposite direction, the change-over switch is operated, and reverses the indications of the direction indicator by reversal of the potential connections. In order to obviate any possible chance of the direction indicator giving an incorrect reading, it derives its field from an electro-magnet energized from the source of supply; so that in the event of the supply system being changed in polarity through any cause, the indications of instrument will always be correct.

ADVANTAGES.

1. Mechanism is electrically operated, thereby permitting distant and multiple indicators.
2. Transmitter requires very little driving torque.
3. Transmitter is not affected by temperature changes or magnetic stray fields.
4. Mechanical wear of parts does not primarily affect the accuracy of calibration.
5. Applicable to a wide range in speeds in either direction.
6. Will indicate fluctuating or pulsating speed changes.
7. Employs no permanent magnets in transmitter. Change in strength of permanent magnets in indicators does not affect the accuracy when the " zero" or " null" method is used.
8. Uniform scale graduations.
9. Not affected by variable supply voltage.
10. The " zero" or " null" method used eliminates most instrument errors common to calibrated deflecting types.
11. Combines a simple telegraph system without adding any special equipment to the indicator system.

DISADVANTAGES.

1. Brushes are required for the interruption and reversal of the current through the transmitter; all forms of brushes inherently wear, oxidize and change resistance at this point during service.

2. The torque of all indicators using the "zero" or "null" method is of low order so that operation is affected by friction of the moving coil.

3. A sensitive moving coil is required for best operation of the indicators. It is difficult to maintain this requirement in combination with ruggedness and high dampening required for Naval ships.

4. Permanency of the adjusted resistance values of the Wheatstone Bridge arms, which is necessary for maintained accuracy, is difficult to attain on Naval ships.

APPLICATION.

The Pulsator Speed and Direction Telegraph System is primarily for use in fixed installations, where distant control of engine or shaft speeds is required, and where high accuracy at all ranges of speeds is required free from mileage logs, total revolutions and average shaft speeds.

CONCLUSION.

From the foregoing analyses of the various types and forms of devices for measuring or indicating speeds, the matter of selecting the most suitable one for a particular installation or test purpose, from the standpoint of prolonged accuracy is for the user, limited somewhat, by the initial cost. This situation might be dramatized as, "What Price Accuracy?" For the designer, the basic limitations of the various types should be given careful study so that their efforts may be employed in perfecting those in which the basic principles of accuracy are on a sound foundation. It is to be conceded that a highly perfected device of unsound principles may give better results and service than one which is sound in principle but which is incompletely designed or poorly fabricated.

Generally speaking, designs are to be avoided in which the indications are Basically dependent on such factors as: permanent magnets; generated voltage or current rectified through commutators and brushes; cables or windings employing metals of appreciable temperatures coefficient; re-action control springs; and centrifugal forces.

If the above eliminations are to be recognized, the field of selection or design in Naval Service can be restricted for use as Revolution Counters, to those devices employing Positive mechanical or electrical drive. For Speed Indicators or Revolutions per Minute Indicators, the field is restricted to those employing Positive mechanical or electrical drive, controlled or timed on the chronometric principle. For Tachometers used to obtain the acceleration, de-accelerations, fluctuations, or peak speeds, it becomes necessary, due to the lack of devices employing basically sound principles, to rely entirely on devices employing centrifugal forces.

AN ADDITIONAL CHART FOR PROPELLER DESIGN BY THE DYSON METHOD.

By E. A. STEVENS, JR., MEMBER.

1. While the pitch, projected area ratio, revolutions per minute and the indicated or shaft horsepower, for a given diameter of propeller and speed of the ship, can be obtained quite readily by the use of the design forms given in "Screw Propellers" by Rear Admiral C. W. Dyson, the characteristics of a wheel and the required power for a given speed are not so quickly obtained when the revolutions are fixed. Under this condition various diameters are assumed and the pitch, projected area ratio, revolutions and indicated or shaft horsepower are calculated. Curves are then drawn using revolutions as abscissas, from which the above mentioned items can be obtained for any desired speed of the engine.

2. If the power and revolutions of the engine are given and it is desired to find the speed that can be obtained, together with the characteristics of the propeller, the problem is still more complicated and if the assumed speed to start the calculations is considerably different from that which can be obtained, the wheel may be too close to the cavitation point, in which case the work should be gone over again, using the value obtained for the actual speed for starting the new calculations.

3. In order to obtain the characteristic of the screw when the revolutions are given the two forms, together with the chart marked "Sheet 20 AA", are given. Form No. 1 is used when the speed of the ship, the effective horsepower and the revolutions of the engines are given, it being desired to find the required indicated or shaft horsepower and the characteristics of the wheel. Form No. 2 is used when the speed

of the ship and indicated or shaft horsepower and revolutions of the engines are given but no effective horsepower curves are available. Form No. 2 can also be used to find the speed that can be obtained together with the characteristics of the propeller when the power and revolutions of the engine are given and effective horsepower curves are available.

4. Form No. 2 is especially convenient for calculating propellers of triple and quadruple screw ships where the revolutions and / or power are not the same on the inner and outer shafts.

5. The Curves on Sheet 20 AA. were obtained as follows:

$$\text{S.H.P.} = \frac{D^2 \times \text{S. } T_d. \times P \times R}{C} \quad . \quad . \quad . \quad \text{(I)}$$

$$\text{As } P \times R = \frac{\text{T. S.} \times P}{\pi \times D} \quad \text{Then } D = \frac{\text{T. S.} \times P.}{\pi \times P \times R} = \frac{\text{T. S.}}{\pi \times R.}$$

Substituting this value of "D" in equation (I) we get

$$\text{S.H.P.} = \left(\frac{\text{T. S.}}{\pi \times R}\right)^2 \times \frac{\text{S.T}_d. \times P \times R}{C} =$$

$$\frac{\text{T.S.}^2 \times \text{S.T}_d. \times P}{\pi^2 \times C \times R} \quad . \quad . \quad . \quad . \quad \text{(II)}$$

$$\text{Then } \frac{\text{T. S.}^2 \times \text{S. } T_d.}{\pi^2} = \frac{\text{S. H. P.} \times R \times C}{P} \quad . \quad . \quad \text{(III)}$$

For convenience in plotting divide both sides of equation (III) by 1,000,000 and letting $C^1 = C \div 100$ we get

$$A^1 = \frac{\text{T. S.}^2 \times \text{S. } T_d.}{\pi^2 \times 1{,}000{,}000} = \frac{\text{S. H. P.} \times R \times C^1}{P \times 10{,}000} \quad . \quad \text{(IV)}$$

Now multiply both sides of equation (IV) by P. C_s and letting $A = A^1 \times \text{P. C.}_s$ we get

$$A = \frac{\text{T. S.}^2 \times \text{S. } T_d. \times \text{P. } C_s}{\pi^2 \times 1{,}000{,}000} = \frac{\text{P.}C_s \times \text{S.H.P.} \times R \times C^1}{P \times 10{,}000} \quad \text{(V)}$$

As P. $C_s \times$ S. H. P. = E. H. P. we have

$$A = \frac{T.S.^2 \times S.T_d. \times P.C_s}{\pi^2 \times 1{,}000{,}000} = \frac{E.H.P. \times R \times C^1}{P \times 10{,}000} \quad . \quad (VI)$$

As S. T_d. × P. C_s. = I. T_d × P. C., equation (VI) can also be written as follows.

$$A = \frac{T.S.^2 \times I.T_d \times P.C}{\pi^2 \times 1{,}000{,}000} = \frac{E.H.P. \times R \times C^1}{P \times 10{,}000}$$

C = 3.89 for 2 Bladed Wheels
2.918 for 3 Bladed Wheels
2.524 for 4 Bladed Wheels

Obtaining values of T. S., S.T_d × P.C_s from Sheet 20A, A and A^1 were calculated for various projected area ratio from which the curves on Sheet 20 AA. were drawn.

6. Forms No. 1 and No. 2 are given at the end of this article. The sheet numbers (except Sheet 20 AA. which is here included) refer to illustrations in Volume II of "Screw Propellers" by Rear Admiral Charles W. Dyson.

7. Before giving any problems to illustrate the use of Sheet 20 AA and the included forms, it would be well to discuss the values of the speed and gross load fractions (v ÷ V and e.h.p_g ÷ E.H.P. lines (4) and (5) on Forms No. 1 and No. 2) that should be chosen, in order that the most efficient propeller may be obtained and at the same time will be out of, or not seriously in, cavitation when conditions are other than those for which the design is made, also the increased resistance of ships in service over trial trip or ideal conditions.

8. When in service the resistance of a ship is somewhat higher than that shown by the model test. This increase depends upon a number of items which have been presented in detail by the author in "Marine Engineering and Shipping Age" May 1926 (Resistance of Ocean Going Ships in Service Compared with Ideal Conditions). This increment for average sea conditions is about 25 per cent for freight ships and 20 per cent for passenger vessels.

9. In choosing the values of v ÷ V and e.h.p_g ÷ E.H.P. two things should be kept in mind. First, the higher the value of the latter the smaller will be the projected area ratio, which tends to reduce both the indicated or shaft horsepower and the weight of the wheel. Second, the lower the value of v ÷ V the smaller will be the diameter for a given R.P.M. and e.h.p_g ÷ E.H.P.

10. When the basic slip of the ship in question is high the value of v ÷ V should be as high as possible so that the greatest possible value of e.h.p_g ÷ E.H.P. can be used, but it should not be too near the value of unity, in order to avoid cavitation due to excess tip speeds (which occur when v ÷ V exceeds 1.0) when conditions are more favorable than those for which the propeller is designed and at the same time this value should be sufficiently above the cavitation curve on Sheet 22 A, so that cavitation will not occur when conditions are somewhat worse than those chosen for the design. Although experience is the best guide, a good rule to follow, when the allowances mentioned in Paragraph 8 have been made for the increase resistance for service conditions, is not to choose a higher value of v ÷ V than .90 and e.h.p_g ÷ E.H.P. is to be such, that the value of v ÷ V on the cavitation curve will be at least 5 per cent less than that chosen.

11. If the ship's basic slip is low, so that any value of e.h.p_g ÷ E.H.P. may be chosen without the propeller being too near cavitation due to either excess tip speed or excess thrusts, this value should not exceed .85 to .90, unless the propeller is being designed for the maximum possible power of the engines, in which case the value of e.h.p_g ÷ E.H.P. may be as high as, or slightly exceed, unity.

12. If the propeller is being designed for the maximum possible speed that can be obtained under the most favorable conditions, the value of v ÷ V may be as high as .97 or .98, or if the draft of the ship varies very slightly, as in most warships, yachts and passenger vessels that carry very little or no freight, the value of v ÷ V may be taken as high as .95.

In most cases where the propeller is designed for the maximum possible speed, no allowances have been made for the increase in resistance for service conditions, so the value of v ÷ V should be at least 12 per cent higher than that of the cavitation curve.

13. If the projected area ratio found by using the highest possible value of e.h.p_g ÷ E.H.P. is too low, take a lower value. In such cases the value of v ÷ V should be not less than 5 per cent greater than that of the cavitation curve at this point for the basic slip of the ship in question. Admiral Dyson states that a projected area ratio of less than .23 (for 3 blades) should not be used.

14. In the problems given in this article allowances for the increased resistance mentioned in Paragraph 8 have been made and, as the ships have been taken at their maximum draft, the highest value of v ÷ V will be taken at .90. The value of e.h.p_g ÷ E.H.P. will be taken so that there will be at least a 5 per cent leeway in the speed fraction before cavitation due to excess thrust occurs.

PROBLEM NO. I.

It will be required to find the indicated horsepower to drive a single screw freight ship at 10.5 knots under average service conditions and the characteristics of the propeller. The following data being given.

Speed in service under average sea conditions	=	10.5 knots.
Effective horsepower under average sea conditions	=	1355
R.P.M. under average service conditions	=	80
Power augment factor K	=	1.25
Basic Slip S	=	.18
Number of propellers		1
Number of blades		4

In order to use the highest possible value of e.h.p_g ÷ E.H.P. as explained in Paragraph 10 the value of v ÷ V (line 4) will be taken at .90. The speed fraction at which

cavitation begins should not be greater than 95 per cent of that chosen, or .90 × .95 = .855. Turning to Sheet 22 A. Chart I (as this ship is one of Type 2) it is found that the cavitation curve for .18 Basic Slip intersects v ÷ V of .855

PROBLEM N° 1

DESIGN FORM N°1

N° of Propellers 1 N° of Blades 4

(1) K	1·25	1·25	1·25					
(2) S	·18	·18	·18					
(3) 1-S	·82	·82	·82					
(4) v÷V	·90	·855	·75					
(5) e.h.p$_g$÷E.H.P.	·69	·60	·40					
(6) $10^{2\cdot5}$ From Sheet 21	1·473	1·70	2·69					
(7) $10^{2\cdot5}$P÷$10^{2\cdot5}$×K=(6)×(1)	1·842	2·125	3·230					
(8) e.h.p.÷E.H.P From Sheet 21	·555	·484	·324					
(9) $10^{2\cdot5}$ From Sheet 21	1·13	1·31	1·91					
(10) s=S×$10^{2\cdot5}$÷$10^{2\cdot5}$=(2)×(9)÷(6)	·138	·139	·133					
(11) 1-s	·862	·861	·867					
(12) v	10·5	10·5	10·5					
(13) R_d	80	80	80					
(14) P=$\frac{v\times 101\cdot33}{R_d\times(1-s)}=\frac{(12)\times 101\cdot33}{(13)\times(11)}$	15·43	15·45	15·34					
(15) R=$\frac{R_d}{v\div V}\times\frac{1-s}{1-S}=\frac{(13)\times(11)}{(4)\times(3)}$	92·4	98·3	112·8					
(16) N×e.h.p.	1355	1355	1355					
(17) N	1	1	1					
(18) e.h.p.=$\frac{N\times e.h.p.}{N}=\frac{(16)}{(17)}$	1355	1355	1355					
(19) E.H.P=$\frac{e.h.p.}{e.h.p.\div EHP}=\frac{(18)}{(5)}$	2440	2800	4180					
(20) A=$\frac{E.H.P_s\times R\times C'}{10,000\times P}=\frac{(19)\times(15)\times C'}{10,000\times(14)}$	3·69	4·50	7·76					
C'=3·98 for 2 bladed wheels, 2·918 for 3 bladed wheels and 2·524 for 4 bladed wheels								
(21) PA÷D.A. From Sheet 20AA	·196	·21	·255					
(22) ⅔ PA÷DA=⅔ or ⅗×(21)			·340					
(23) P.C. From Sheet 20A			·655					
(24) I.H.P$_s$ E.H.P÷P.C.=(19)÷(23)			6350					
(24a) S.H.P$_s$ E.H.P÷P.C.=(19)÷(23)			——					
(25) I.H.P$_s$=I.H.P$_s$÷$10^{2\cdot5}$=(24)÷(6)			2450					
(25a) S.H.P$_s$=S.H.P$_s$÷$10^{2\cdot5}$=(24a)÷(6)			——					
(26) N×I.H.P$_s$=(17)×(25)			2450					
(26a) N×S.H.P$_s$=(17)×(25a)			——					
(27) T.S. From Sheet 20A			6050					
(28) D=$\frac{T.S.}{\pi\times R}=\frac{(27)}{\pi\times(15)}$			17.07					

at the abscissa value of .71, which is the highest value of e.h.p$_g$ ÷ E.H.P. (line 5) that should be taken. In this problem .69 has been taken for the gross load fraction. Use Form No. 1 for this problem.

Going through the calculations as far as line (21) it is found that the projected area ratio of 3 blades is .196, which is too

low. Taking a value of e.h.p_g ÷ E.H.P. of .60 it is found that cavitation begins when v ÷ V equals .81, then the lowest value of the speed fraction should be .81 ÷ .95 = .853. In this case .855 has been taken. Going through the calculations again, as shown in the second column, it is found that the projected area ratio of 3 blades is .21. This also is too low. Taking the gross load fraction at .40 and finding the value of the speed fraction as just described, we find the power and characteristics of the propeller to be the following:

I.H.P.	— 2450
Diameter in feet	— 17.07
Pitch in feet	— 15.34
P.A. ÷ D.A. (4 blades)	— .340
R.P.M.	— 80

If any auxiliaries are attached to the main engines the power should be increased by the amounts shown below.

Main air pump	— 3.0 per cent
Engine room bilge pump	— .5 per cent
Sanitary pump	— 1.0 per cent
Feed pump	— 2.0 per cent

PROBLEM NO. 2.

Twin screw passenger ship fitted with geared turbines

Number of propellers	— 2
Number of blades	— 3
Total shaft horsepower on both shafts	— 12,000
R.P.M.	— 110
Power augment factor K	— 1.14
Basic Slip S	— .15

Ship is of Type 2. Effective horsepower curves from model test are given, to which is added 20 per cent to allow for service conditions. The characteristics of the propeller and speed of the ship are to be found. Form 2 will be used.

In order to start the calculations, it is necessary to assume the speed of the ship (v line 12) which should be as close as

possible to the actual. From experience with ships of this class it has been found, that the actual propulsive coefficient $p.c_s$ (not the Basic Propulsive Coefficient $P.C_s$) will be about .60 or better. The actual effective horsepower (assuming $p.c_s = .60$) will then be $.60 \times 12{,}000 = 7200$. From the

PROBLEM N° 2
DESIGN FORM N°2

N° of Propellers 2 N° of Blades 3

(1) K	1.14	1.14
(2) S	.15	.15
(3) 1-S	.85	.85
(4) $v \div V$	.90	.90
(5) e.h.p. $\div$ E.H.P	.80	.80
(6) $10^{2.5}$ From Sheet 21	1.262	1.262
(7) $10^{2.5} \times 10^{2.5} \times K \div (6) \times (1)$	1.439	1.439
(8) e.h.p $\div$ E.H.P. From Sheet 21	.706	.706
(9) $10^{2.5}$ From Sheet 21	1.13	1.13
(10) $s \cdot S \times 10^{2.5} \div 10^{2.5} \times (2) \times (9) \div (6)$	.134	.134
(11) 1-s	.866	.866
(12) v	16.6	17.07
(13) R_d	110	110
(14) $P = \frac{v \times 101.33}{R_d \times (1-s)} = \frac{(12) \times 101.33}{(13) \times (11)}$	17.65	18.16
(15) $R = \frac{R_d}{v \div V} \times \frac{1-s}{1-S} = \frac{(13) \times (11)}{(4) \times (3)}$	124.5	124.5
(16) $N \times I.H.P_d$.	—	—
(17) $N \times S.H.P_s \cdot N \times I.H.P_s \times$ Mech. Eff.	12000	12000
(18) N	2	2
(19) $S.H.P_s \cdot (N \times S.H.P_s) \div N \cdot (17) \div (18)$	6000	6000
(20) $S.H.P. \cdot S.H.P_s \times 10^{2.5} \cdot (19) \times (6)$	7570	7670
(21) $A' = \frac{S.H.P. \times R \times C'}{10{,}000 \times P} = \frac{(20) \times (15) \times C'}{10{,}000 \times (14)}$	15.58	15.15
C' = 3.98 for 2 bladed wheels, = 2.918 for 3 bladed wheels and 2.524 for 4 bladed wheels		
(22) P.A $\div$ D.A. From Sheet 20AA	.297	.294
(23) $\frac{3}{2}$ or $\frac{2}{3}$ P.A $\div$ D.A $\div \frac{3}{2}$ or $\frac{2}{3} \times$ (22)	—	—
(24) P. C_s From Sheet 20A	.739	.741
(25) E.H.P $\cdot$ S.H.P $\times$ P.$C_s \cdot (20) \times (24)$	5595	5610
(26) e.h.p $\cdot$ E.H.P $\cdot (v \div V \text{ or } V \div v) \cdot (25) \times (8)$	3950	3960
(27) $N \times$ e.h.p $\cdot (18) \times (26)$	7900	7920
(28) T.S From Sheet 20A	6730	6690
(29) $D = \frac{T.S.}{\pi \times R} \cdot \frac{(28)}{\pi \times (10)}$	17.19	17.10

effective horsepower curve, corrected for sea conditions, it is found that this corresponds to a speed of 16.6 knots, which will be used as the valve of v line (12) column No. 1. It will be found that the total effective horsepower ($N \times$ e.h.p. line 27) is 7900 which is somewhat higher than that estimated. Turning to the effective horsepower curve we find that the corresponding speed is 17.07 knots. Using this for

v (line 12, column 2) it will be found that the total effective horsepower (N × e.h.p.) will be 7920 which is close enough to that from the curve for this speed (17.07 knots). The data found will then be:

Speed in service in knots	—	17.07
Diameter in feet	—	17.10
Pitch in feet	—	18.16
Projected area ratio	—	.294
$p.c_s = \frac{N \times e.h.p.}{N \times S.H.P_d}$	—	.65

When there is not much difference in the assumed speed (v line 12, column No. 1) and that from the e.h.p. curve corresponding to N × e.h.p. (line 27, column 1) the differences in diameters and projected area ratios of the two propellers (as found in this problem) are very slight and these characteristics of the first wheel may be taken for the final. The final pitch can be found as follows:

Let v_1 = Assumed speed line (12) column 1.
v_2 = Speed from e.h.p. curve corresponding to N × e.h.p. line 27, column 1.
P_1 = Pitch as found in column 1, line 14.
P_2 = Final pitch.
Then $P_2 = P_1 \times v_2 \div v_1$

PROBLEM NO. 3.

This problem will illustrate the use of Form No. 2 for finding the characteristics of the propellers and the speed that may be expected of a ship fitted with more than two screws when the power and revolutions on the inner and outer shafts are not the same. The effective horsepower curve, revolutions and power being given.

The ship in question is a large passenger liner fitted with four shafts, the inner ones being connected to reciprocating engines while the outer are driven with turbines. The indicated horsepower of the reciprocating engines and shaft horsepower of the turbines being given below. For convenience

shaft horsepower on all shafts will be used in the calculations. As there will be no auxiliaries attached to the reciprocating engines their mechanical efficiency is taken at .92.

PROBLEM N° 3

DESIGN FORM N°2

N° of Propellers 4 — N° of Blades 3

	Outer	Inner	Outer	Inner
(1) K	1.097	1.115	1.097	1.115
(2) S	.15	.117	.15	.117
(3) 1-S	.85	.883	.85	.883
(4) v ÷ V	.90	.90	.90	.90
(5) e.h.p ÷ E.H.P.	.80	.80	.80	.80
(6) $10^{\frac{2}{3}}$ From Sheet 21	1.262	1.262	1.262	1.262
(7) $10^{\frac{2}{3}} \times 10^{\frac{2}{3}} \times K \times (6) \times (1)$	1.385	1.407	1.385	1.407
(8) e.h.p ÷ E.H.P. From Sheet 21	.732	.721	.732	.721
(9) $10^{\frac{2}{3}}$ From Sheet 21	1.13	1.13	1.13	1.13
(10) $S \times 5 \times 10^{\frac{2}{3}} \times 10^{\frac{2}{3}} \times (2) \times (9) \div (6)$	.134	.10	.134	.10
(11) 1-s	.866	.90	.866	.90
(12) v	22.5	22.5	22.9	22.9
(13) R_d	150	80	150	80
(14) $P = \frac{v \times 101.33}{R_d \times (1-s)} = \frac{(12) \times 101.33}{(13) \times (11)}$	17.57	31.70	17.98	32.25
(15) $R = \frac{R_d}{v \div V} \times \frac{1-s}{1-S} = \frac{(13) \times (11)}{(4) \times (3)}$	170	90.6	170	90.6
(16) N x I.H.P$_d$.	——	30000	——	30000
(17) N x S.H.P$_d$ = N x I.H.P$_d$ x Mech. Eff.	30000	27600	30000	27600
(18) N	2	2	2	2
(19) S.H.P$_d$ = (N x S.H.P$_d$) ÷ N = (17) ÷ (18)	15000	13800	15000	13800
(20) S.H.P = S.H.P$_d$ x $10^{\frac{2}{3}}$ = (19) x (6)	18930	17410	18930	17400
(21) $A' = \frac{S.H.P \times R \times C'}{10,000 \times P} = \frac{(20) \times (15) \times C'}{10,000 \times (14)}$	53.45	14.52	52.20	14.29
C' = 3.98 for 2 bladed wheels, = 2.918 for 3 bladed wheels and 2.524 for 4 bladed wheels				
(22) P.A ÷ D.A. From Sheet 20AA	.433	.29	.43	.288
(23) $\frac{2}{3}$ or $\frac{3}{5}$ P.A ÷ D.A = $\frac{2}{3}$ or $\frac{3}{5}$ x (22)	——	——	——	——
(24) P.C$_s$. From Sheet 20A	.65	.743	.653	.745
(25) E.H.P = S.H.P x P.C$_s$ = (20) x (24)	12300	12950	12360	12975
(26) e.h.p = E.H.P ÷ (e.h.p ÷ E.H.P) = (25) ÷ (8)	9000	9330	9050	9360
(27) N x e.h.p. = (18) x (26)	18000	18660	18100	18720
(28) T.S. From Sheet 20A	9150	6620	9100	6570
(29) $D = \frac{T.S.}{\pi \times R} = \frac{(28)}{\pi \times (18)}$	17.12	23.25	17.03	23.07
N x e.h.p on 4 Shafts	36660		36820	

Position of propellers	Inner	Outer
Number of propellers	2	2
Number of blades	3	3
Total indicated horsepower	30,000	....
Total shaft horsepower	27,600	30,000
Revolutions per minute	80	150
Power augment factor K	1.117	1.097
Basic Slip S	.117	.15

In order to obtain the approximate speed in order to start the calculations, as explained in Problem No. 2, the actual propulsive coefficient p.c_s will be taken at .60. The total effective horsepower delivered by all four shafts with this propulsive coefficient will be 34,600 which corresponds to a speed of 22.5 knots.

DESIGN FORM No 1

(1)	K	Power Augment Factor
(2)	S	Basic Slip
(3)	1-S	1 - Basic Slip
(4)	$v \div V$	Speed Fraction
(5)	$e.h.p_3 \div E.H.P$	Gross Load Fraction
(6)	10^{-3}	Gross Load Factor from Sheet 21 corresponding to $e.h.p_3 \div E.H.P$ line (5)
(7)	$10^{-3} P = 10^{-3} \times K$	(6)x(1) Net Load Factor
(8)	$e.h.p_4 \div E.H.P$	Net Load Fraction from Sheet 21 corresponding to $10^{-3}P$ line (7)
(9)	$10^{-2} s$	Speed Factor from Sheet 21 corresponding to $v \div V$ line (4)
(10)	$s = S \times 10^{-2} \div 10^{-2} s$	(2)x(9) ÷ (6) = Estimated Apparent Slip
(11)	$1 - s$	1 - Estimated Apparent Slip
(12)	v	Desired Speed in Knots
(13)	R_d	Desired R.P.M.
(14)	$P = \frac{V \times 101.33}{R_d \times (1-s)}$	$\frac{(12) \times 101.33}{(13) \times (11)}$ Pitch in Feet
(15)	$R = \frac{R_d}{v \div V} \times \frac{1-s}{1-S}$	$\frac{(13) \times (11)}{(4) \times (3)}$ Basic R.P.M.
(16)	$N \times e.h.p$	Total Effective Horse Power on all shafts
(17)	N	Number of shafts
(18)	$e.h.p = (N \times e.h.p) \div N$	(16) ÷ (17) Effective Horse Power on one shaft
(19)	$E.H.P = e.h.p \div (e.h.p \div E.H.P)$	(18) ÷ (8) Basic Effective Horse Power on one shaft
(20)	$A = \frac{E.H.P \times R \times c'}{10,000 \times P}$	$\frac{(19) \times (15) \times C'}{10,000 \times (14)}$ C' = 3.09 for 2 bladed wheels C' = 2.918 " 3 " " C' = 2.524 " 4 " "
(21)	$P.A. \div D.A$	From Sheet 20 A A = Projected Area Ratio of 3 blades
(22)	$\frac{2}{3} \times P.A \div D.A.$	$\frac{2}{3}$ x (21) = " " " " " 4 "
(22a)	$\frac{1}{2} \times P.A \div D.A$	$\frac{1}{2}$ x (21) = " " " " " 2 "
(23)	P C or $P C_s$	From Sheet 20 A Basic Propulsive Coefficient Corresponding To P.A ÷ D.A [line (21)] for 3 bladed wheels " " $\frac{2}{3}$ P.A ÷ D.A [line (22)] " 4 " " " " $\frac{1}{2}$ P.A ÷ D.A [line (22a)] " 2 " "
(24)	$I.H.P = E.H.P \div P C_s$	(19) ÷ (23) = Basic Indicated Horse Power on one shaft
(24a)	$S.H.P = E.H.P \div P C_s$	(19) ÷ (23) " Shaft " " " " " "
(25)	$I.H.P_d = I.H.P \div 10^{-3}$	(24) ÷ (6) Estimated Indicated Horse Power on one shaft
(25a)	$S.H.P_d = S.H.P \div 10^{-3}$	(24a) ÷ (6) " Shaft " " " " " "
(26)	$N \times I.H.P_d$	(25) x (17) " Indicated " " " all shafts
(26a)	$N \times S.H.P_d$	(25a) x (17) " Shaft " " " " "
(27)	T.S.	From Sheet 20 A Basic Tip Speed in feet per minute corresponding to P.A ÷ D.A [line (21)] for 2, 3 and 4 bladed wheels
(28)	$D = \frac{T.S}{\pi \times R}$	$\frac{(27)}{\pi \times (15)}$ = Diameter in feet

From the calculations in the first two columns it is found that the total effective horsepower delivered by four shafts is 36,660 which is somewhat higher than that assumed to obtain the approximate speed (v line 12, columns 1 and 2) to start the calculations. Turning to the effective horsepower

curves, we find the speed corresponding to 36,660 e.h.p. is 22.9 knots which is used for the value of v in columns 3 and 4. As the effective horsepower from all shafts as found from columns 3 and 4 is within one per cent of that from the curve for the speed, the results found can be taken as final. The following is the data found.

DESIGN FORM No 2

(1) K	Power Augment Factor
(2) S	Basic Slip
(3) 1-S	1- Basic Slip
(4) $v \div V$	Speed Fraction
(5) $e.h.p_s \div E.H.P$	Gross Load Factor
(6) $10^{2\cdot S}$	Gross Load Factor from Sheet 21 corresponding to $e.h.p_s \div E.H.P$ line (5)
(7) $10^{2\cdot P} = 10^{2\cdot S} \times K$	= (6) x (1) = Net Load Factor
(8) $e.h.p \div E.H.P.$	Net Load Fraction from Sheet 21 corresponding to $10^{2\cdot P}$ line (7)
(9) $10^{2\cdot s}$	Speed Factor from Sheet 21 corresponding to $v \div V$ line (4)
(10) $s = S \times 10^{2\cdot S} \div 10^{2\cdot S}$	(2) x (9) ÷ (6) Estimated Apparent Slip
(11) 1-s	1- Estimated Apparent Slip
(12) v	Desired Speed in Knots
(13) R_d	Desired R.P.M.
(14) $P = \frac{v \times 101.33}{R_d \times (1-s)}$	$= \frac{(12) \times 101.33}{(13) \times (11)}$ = Pitch in Feet
(15) $R = \frac{R_d}{v \div V} \times \frac{1-s}{1-S}$	$= \frac{(13) \times (11)}{(4) \times (3)}$ = Basic R.P.M.
(16) $N \times I.H.P_d$	Total Indicated Horse Power on all shafts
(17) $N \times S.H.P_d = N \times I.H.P_d \times M.E.$	(16) x Mechanical Efficiency = Total Shaft Horse Power on all shafts
(18) N	Number of Shafts
(19) $S.H.P_d = (N \times S.H.P_d) \div N$	(17) ÷ (18) Shaft Horse Power on one shaft
(20) $S.H.P = S.H.P_d \times 10^{2\cdot S}$	(19) x (6) Basic Shaft Horse Power on one shaft
(21) $A' = \frac{S.H.P \times R \times C'}{10,000 \times P}$	$= \frac{(20) \times (15) \times C'}{10,000 \times (14)}$ C' = 3.89 for 2 bladed wheels C' = 2.918 " 3 " " C' = 2.524 " 4 " "
(22) P.A ÷ D.A.	From Sheet 20AA = Projected Area Ratio of 3 blades
(23) ⅔ P.A ÷ D.A.	= ⅔ x (22) " " " " " 4 "
(23a) ⅔ P.A ÷ D.A	= ⅔ x (22) " " " " " 2 "
(24) $P.C_s$	From Sheet 20A = Basic Propulsive Coefficient Corresponding to P.A ÷ D.A. [line (22)] for 3 bladed wheels " " ⅔ P.A ÷ D.A. [line (23)] " 4 " " " " ⅔ P.A ÷ D.A. [line (23a)] " 2 " "
(25) $E.H.P = S.H.P \times PC_s$	= (20) x (24) Basic Effective Horse Power on one shaft
(26) $e.h.p = E.H.P \times (e.h.p \div E.H.P)$	= (25) x (8) Effective Horse Power delivered by one shaft
(27) $N \times e.h.p$	= (18) x (26) Total Effective Horse Power " " all shafts
(28) T.S	From Sheet 20A Basic Tip Speed in feet per minute corresponding to P.A ÷ D.A. [line (22)] for 2, 3 and 4 bladed wheels
(29) $D = \frac{T.S}{\pi \times R.}$	$\frac{(28)}{\pi \times (13)}$ Diameter in feet

Position of propellers	Inner	Outer
Diameter in feet	23.07	17.03
Pitch in feet	32.25	17.98
Projected area ratio	.288	.43
Speed	22.9	

It can be seen by anyone who has used the Dyson method, that considerable time can be saved in designing propellers by using Sheet 20 AA. when full diameters can be carried. If the location of the wheel is such that it is necessary to resort to propellers of reduced diameters, no appreciable time can be saved by using the method here described. Before closing the writer wishes to express his appreciation for the assistance given by Mr. J. S. Malseed in preparing this article.

TRANSMISSION AND REMOVAL OF HEAT BY THE COOLING SYSTEM OF DIESEL ENGINES.

By Lieutenant William Wakefield, U. S. Navy, Member.

In looking over any heat balance sheet of a Diesel engine it will be seen that the greatest loss of the heat of combustion is that rejected to the cooling water. Apart from very slight losses, such as radiation, etc., the total heat generated may be divided into various values, which are found experimentally and which, when arranged in order of percentages, form a method of accounting for the utilization of this heat.

Total heat supplied	100 per cent
Accounted for by indicated work	42 per cent
Rejected to cooling water	34 per cent
Rejected to exhaust	24 per cent

This typical heat balance could apply to almost any internal combustion engine, and the striking feature is the large amount of heat appearing on the cooling water account, which at first sight would appear to indicate very poor utilization of heat within the cylinder. However, it has been shown that a large proportion of the heat received by the cooling water is given out by the exhaust gases after combustion is complete, particularly on their passage through the cylinder cover or through the cylinder parts. Most of the friction work done by the piston and all the compressor work appear on the cooling water account.

The transfer of heat from the time of combustion until it reaches the cooling medium is the biggest problem that confronts the designer of large Diesel engines today. This question has two phases:

(*a*) The transfer of heat of combustion to the metal walls of the combustion chamber.

(*b*) The transfer of heat through the combustion chamber walls to the cooling medium.

It is fairly well established among the leading engineers and investigators that the heat of combustion is conveyed to the chamber walls wholly by radiation. Some heat due to compression may be transferred by convection, but the relative amount would be small. Obviously the heat through the walls is transferred by conduction.

The gases at the time of combustion when the heat is first generated, will be an incandescent body composed of innumerable molecules, each with vibrations according to its nature and temperature, sending out radiations of various wave lengths. They not only send out light of various wave lengths but also heat, which has wave lengths relatively longer than those of light. In any case the radiations of light and of heat are similar, those waves constituting light being short, those of heat relatively long. Conclusive evidence of this similarity is furnished by the fact that heat radiations obey the same laws of reflection, refraction, polarization, and interference as light radiations, the difference being only in the way they affect our senses. From this it can be readily understood that a body is capable of absorbing its own radiations. For instance, the radiations emitted by a uniformly constituted hot gas, if allowed to fall on gas of the same constitution would be absorbed by the latter. Thus it is that the radiation of heat from a flaming gas comes principally from the surface of the flame, since the greater part of the radiations from the interior of the flame are probably absorbed by the surrounding gas of the same constitution, and therefore do not reach the surface of the flame. It should be noted, however, that the greater the mass of the gas the longer will the body of the gas preserve the temperature or intensity of the radiations.

This last sentence is well worth analyzing and pointing out its application to the design of large Diesel cylinders. As long as the cylinder sizes remained below about thirty inches in diameter not much trouble was experienced with cracked heads, cylinder liners, etc., but as sizes increased to the neighborhood of thirty inches the builders met with innumerable failures through cracking because they treated this phase of the problem as accidental and not fundamental. The rate of heat flow increases with the size of the combustion chamber, because almost all of the heat lost

to the jacket is by radiation which increases with the depth of the flame.

This agrees with some of the investigators who have worked along the theory and well-known law of Stefan and Boltzmann which is now quite generally accepted. According to this law heat will be radiated from an incandescent "black" body according to the following equation:

$$H_t = 16 \times 10^{-10} (T_1^4 - T_2^4)$$

Where:

H_t is the B.T.U. per hour radiated per square foot of radiating body, T_1 equals absolute temperature (F. degrees) of the "black" body, T_2 equals absolute temperature (F. degrees) of the receiving body. A "black" body is defined as one capable of absorbing all heat rays received, neither reflecting nor transmitting any. Hot gases as found in the combustion chamber are not "black" and therefore do reflect some heat received and fail to radiate to the same extent as a "black" body, but as the temperature of the gases at combustion cannot be measured with any degree of accuracy, the results found then in the case of the combustion chamber can only be qualitative, but will be sufficient to illustrate the radiation heat reception of the chamber walls with temperature variation. This is best shown by a graphical representation of the above law, taking arbitrarily, values of temperature and substituting them in the equation a curve can be plotted.

Reducing H_t to B.T.U. per second per square inch, this curve, Figure 1, shows how rapid the rise in heat transfer takes place after the temperature has reached about 1500 degrees F., perhaps the temperature at which incandescence is reached.

Although it is impossible to estimate, separately, the exact amount of heat radiated to the combustion chamber walls, it is probable that the loss by radiation is proportional to the area of wall surface exposed, and practically independent of the time, since the period of duration of the flame and hot gases is short.

From this, the heat lost by radiation to the cylinder walls during combustion is independent of the piston speed.

For small flames, Professor Callendar has shown by measurements of the radiations, that the amount of radiated heat was proportional to the volume of the flames. But as the volume in-

creased into what might be termed a large flame (over 3 centimeters in diameter) the radiations tended toward a finite limit. As the flame is increased the radiations will also increase, although not in proportion to the volume of the flame.

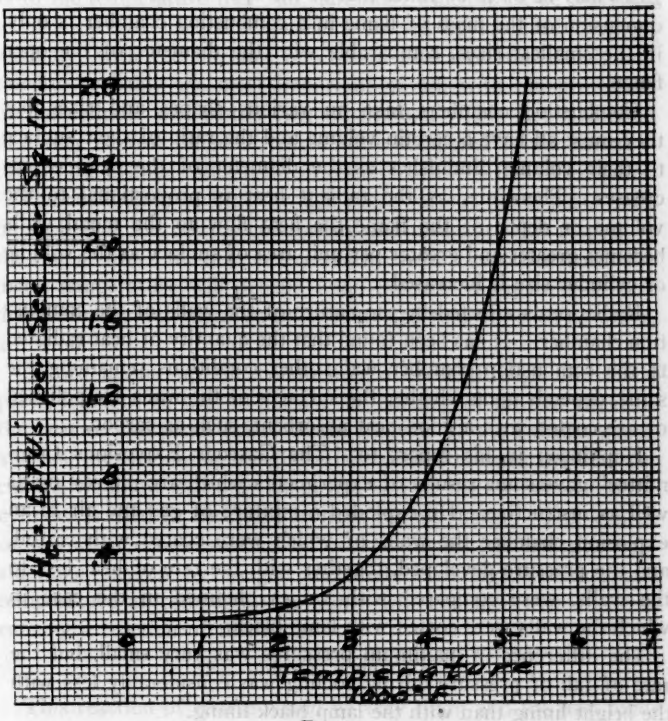


FIG. 1.

Of course these measurements are based on "open flames" and the results are very different from those under the conditions in the combustion chamber of a Diesel engine. However, the qualitative results are important, and fairly demonstrate the significance of the tremendous heat reception by the combustion chamber

of Diesel engines when their volumes and surfaces reach the larger dimensions of today.

The particular difference between the "open flame" and the combustion chamber is the lateral extension and the density. In the combustion chamber during combustion the density of the gases may be 30 to 35 times that of the open flame, while the least dimension of the mass of flame in a combustion chamber is only, in the smallest sizes, comparable with the diameter of the open flame.

Combustion chambers take on various shapes and sizes but they must all have a certain volume and the ratio of their surface to their volume diminishes as the diameter of the cylinder increases. Therefore, as the radiant heat is proportional to the volume or depth of the flame the heat flow to the metal walls becomes greater and greater per unit area of surface as the volume or cylinder size is increased.

Radiation is affected by the nature of the walls of the combustion chamber. It has been found that the quantity of heat radiated to the combustion chamber wall, other conditions remaining the same, depends upon whether the surfaces of the walls are polished or are coated with a good heat absorbent, such as carbon.

Hopkinson in his report to "The Gaseous Explosions Committee" gave some results of experiments which are interesting as well as instructive. He exploded a mixture of gas and air in an explosion chamber the walls of which were coated with tinfoil, and the pressure developed, together with the rate of heat loss to the walls, were compared with values obtained in the case in which the walls were coated with lamp black.

The difference in maximum pressures was very small, but the rate of fall of pressure during cooling was considerably less with the bright lining than with the lamp black lining.

Experiments made on gas engines with polished combustion chambers also show that a perceptible increase in mean effective pressure results.

These results would tend to show that the heat efficiency and mean effective pressure of an internal combustion engine will be appreciably greater with a polished combustion chamber than with a carbon-coated surface. Which again substantiates the theory

that the principal part of the heat to the combustion chamber walls is radiant.

In taking up the second phase of the passage of the heat to the cooling medium, we get into the big problem of Diesel engine design, because it deals, firstly, with metal parts which are limited as to the temperature they can stand and which must be designed to take care of unequal expansions caused by localized heating; secondly, with the burning or erosion effect on the metal, and thirdly, probably the most important of all, with the protection of the cylinder and piston ring lubrication. This last is limited to a very narrow range of temperature compared to the temperature in the cylinder and in direct contact with the lubricated parts.

The conduction of heat through these various metal parts must be such that the flow is continuous and constant with respect to the rate at which the heat is received by them. In other words the metal temperature will depend upon the heat dissipation or heat disposition by that metal to some source of removal such as water, air or oil.

Before taking up the conduction of heat through the metal parts, it might be well to discuss the burning or erosive effect of the heat on the metal skin. From analysis of the exhaust gases, and also by calculating weight of air needed to burn the fuel per charge, we know that only about one-half of the air taken into the cylinder is used or necessary to burn the oil charge. This charge of air when compressed to 30 or 35 atmospheric contains considerable oxygen by weight and under the high pressure and temperature at combustion certainly will combine with the iron causing a reaction of this order—

$$2FE \text{ plus } O_2 \text{ equals } Fe\ O.$$

This reaction of course would be very slight and the iron oxide produced not appreciable probably, but enough nevertheless to affect the skin by wiping away an infinitesimal film of metal each cycle.

The conduction of the heat by the combustion chamber walls is done in several steps or processes which are not very simple in their action, when it is remembered that there is always a film of gas clinging to the exposed combustion chamber walls and in addi-

tion a thin film of oil and perhaps some carbon deposits which all lie between the hot gases and the metal wall.

On the water side of the metal wall or that side which contains the cooling medium we also have films which the heat must pass through before entering this cooling medium. If water is used to cool with, then most likely there will be first a scale or sedimentary deposit and then the water film. Hence we see that before the heat gets to the cooling medium it passes through several resistance paths. Each of these paths forms a different temperature gradient which largely governs the heat flow.

The "thermal resistance" of various substances of different thickness varies inversely as their conductivities, and inversely as their thicknesses or—the resistance to heat flow equals R_t.

$$R_t = \frac{c}{Kd}$$

K equals conductivity.

d equals thickness.

c equals a constant.

But in the case of gaseous and liquid films this value is at best only a poor guess and so far no satisfactory results have been obtained in measuring the conductivity of films of various substances directly.

However, the heat flow can be calculated for a given time if the difference in temperatures between the two sides of the walls of a given thickness are known.

And further, for a given heat flow through different thicknesses of various substances, the temperature drop necessary for this given flow will be proportional to the "thermal resistance" of the substance as defined above.

For approximate calculation, if T_0 and T_1 are the temperatures of the inner and outer surfaces of the cylinder wall, where "d" equals thickness and "k" equals conductivity, then the heat flow for unit time and area will $= \frac{T_0 - T_1}{d} \times K$. Putting this into usable form with "k" in C.G.S. units and, letting "t" equal time in seconds, "A" equal area in square centimeters and "d" the thickness

in centimeters, we have the heat flowing in time "t" seconds expressed in:

$$\text{B. T. U.} = \frac{K\,(T_0 - T_1)}{d} \times A \times t$$

For the purpose of illustrating the nature of the relative resistances offered to the transfer of heat in the case of a Diesel engine cylinder Figure 2 is reproduced—

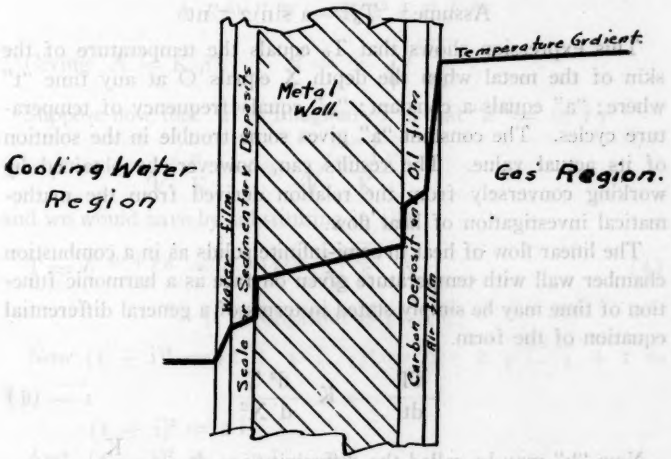


FIG. 2.

The relative temperature gradients are shown quantitively in this figure; the resistances offered to the heat flow are also indicated by these temperature gradients.

This diagram pictures how very high the resistance of the gas film is compared with that of the liquid films.

The fall of temperature in the metal itself is very small, comparatively speaking, but in each case of the contact of the metal surface with the film there is an appreciable drop; this change of contact surface causes a drop in temperature which is analogous to the potential difference set up electrically between the surfaces of contact of two different metals.

The total resistance offered to the flow of heat is the total of the respective resistances shown.

The temperature of the side of the metal walls exposed to the hot gases is continually changing with time, and periodically undergoes a cycle of changes.

This cyclical variation of temperature causes waves of heat to travel into the metal walls of the combustion chamber.

The simplest form of these temperature oscillations can best be represented by the sine law of variation.

$$\text{Assume: } T_0 = a \sin 2\pi nt$$

This expression shows that T_0 equals the temperature of the skin of the metal when the depth X equals O at any time "t" where: "a" equals a constant; "n" equals frequency of temperature cycles. The constant "a" gives some trouble in the solution of its actual value. The results can, however, be obtained by working conversely from the relation derived from the mathematical investigation of heat flow.

The linear flow of heat in semi-infinite solids as in a combustion chamber wall with temperature given on face as a harmonic function of time may be simply stated in terms of a general differential equation of the form.

$$\frac{dT}{dt} = K \frac{d^2 T}{d X^2} \qquad (1)$$

Now "k" may be called the diffusivity i. e. $k = \frac{K}{s\delta}$

Where K is the conductivity
s is the specific heat
δ is the density

Therefore "k" will be a constant.

Now assuming the temperature for X = O to have the form,

$$T = A \sin nt \qquad (2)$$

and $T \neq \propto$ when $X = \propto$

Try as a solution for the above

$$T = E^{\alpha t + \beta x} = E^{\alpha t} E^{\beta x} \qquad (3)$$

Now in order to satisfy (1) we would have

$$\frac{dT}{dt} = E^{\beta x}(a\,E^{at})$$

and $$\frac{dT}{dX} = E^{at}(\beta\,E^{\beta x})$$

$$\frac{d^2T}{dX^2} = E^{at}(\beta^2\,E^{\beta x})$$

So that substituting in (1) we have

$$A\,E^{at}\,E^{\beta x} = K\,\beta^2\,E^{at}\,E^{\beta x}$$

Giving $A = K\,\beta^2 \qquad \beta = \pm\sqrt{\frac{a}{K}}$

Suppose now that "a" is imaginary i. e. that "a" $= \pm i\,\gamma$

then $\beta = \pm\sqrt{\frac{a}{K}} = \pm\sqrt{\frac{\pm i\,\gamma}{K}}$.

and we would have by substituting in (3)

$$T = E^{at+\beta x} = E^{\pm i\gamma t \pm \sqrt{\frac{\pm i\gamma}{K}}\,X} \qquad (4)$$

(i throughout is $\sqrt{-1}$)

Now $(1+i)^2 = (1+\sqrt{-1})^2 = 1 + 2\sqrt{-1} + 1 = 2\sqrt{-1}$

$$(1+i)^2 = 2i$$

And $(1-i)^2 = -2i$

So that $+\sqrt{i} = \frac{1+i}{\sqrt{2}}$

And $-\sqrt{i} = \frac{1-i}{\sqrt{2}}$

Now substitute in equation (4)

$$T = E^{\pm i\gamma t \pm \sqrt{\frac{\pm i\gamma}{K}}\,X} = E^{\pm i\gamma t \pm \sqrt{\frac{\gamma}{K}}\left(\frac{1\pm i}{\sqrt{2}}\right)X}$$

or rewriting

$$T = E^{\pm i\gamma t \pm \sqrt{\frac{\gamma}{2K}}(1\pm i)\,X}$$

And further

$$T = E^{\pm\sqrt{\frac{\gamma}{2K}}x + i\,(\pm\gamma t \pm \sqrt{\frac{\gamma}{2K}}x)}$$

This satisfies the differential equation but in order to satisfy the condition $T \neq \infty$ when $X = \infty$ we must use only the $-$ signs in front of the radical $\sqrt{\frac{\gamma}{2K}}$ (if we used the $+$ sign we would have $E^{+\infty} = \infty$ while $E^{-\infty} = 0$ which satisfies)

We may now write

$$T = E^{-\sqrt{\frac{\gamma}{2K}}x}\left[A\,E^{+i\,(\gamma t - \sqrt{\frac{\gamma}{2K}}x)} + B\,E^{-i\,(\gamma t - \sqrt{\frac{\gamma}{2K}}x)}\right]$$

Where A and B are constants.

But we have given that when $X = O$, T must be of the form

$$T = A \sin nt$$

so that the square bracket must become

$$\sin\left(\gamma t - \sqrt{\frac{\gamma}{2K}}X\right)$$

Where $\gamma = n$ for when $x = O$

$$\sin\left(\gamma t - \sqrt{\frac{\gamma}{2K}}X\right) = \sin \gamma t = \sin nt.$$

The general solution is therefore

$$T = A\,E^{-\sqrt{\frac{n}{2K}}x} \sin\left(n t - \sqrt{\frac{n}{2K}}X\right)$$

Now to get this back into the form as given first, the "n" was substituted for $2\pi n$ and "k" for $\frac{K}{s\delta}$ therefore substituting so as to correspond to the first notation,

$$T = A\,E^{-\sqrt{\frac{2\pi n}{2K}}x} \sin\left(2\pi n t - \sqrt{\frac{\psi \pi n}{\psi K}}X\right)$$

$$\sqrt{\frac{\psi \pi n}{\psi K}} = \sqrt{\frac{\pi n \delta s}{K}} = a$$

and we have

$$T = A\,E^{-ax} \sin(2\pi n t - a x)$$

Which is true only to the extent of the correctness of the assumptions that we started out with, which gives the temperature at any depth "X" of the metal of a solid infinite mass of material with one surface exposed to a sine variation of temperature of frequency "n."

For approximate purposes we can use this relation for walls of thick cylinders.

Let T_1 = average temperature of inner wall
T_2 = temperature of outer wall
d = thickness of walls in inches
A = area of surface in square inches

$$a = \pm \sqrt{\frac{\pi\, n\, \delta\, s}{K}}$$

t = time in seconds
n = frequency of temperature cycles per second
x = any depth in the walls in inches
δ = density of material
s = specific heat of material

Then the expression

$$T = A\, E^{-a\,x} \sin (2\,\pi\, n\, t - a\, x) + T_2 + \frac{T_2 - T_1}{d}\, x$$

gives the temperature at any depth "x" in walls under these conditions.

These mathematical expressions are well known and have not been used here to introduce anything from a practical point of view, but they show that if proper values are substituted for the constants, the cyclic fluctuation die out after passing a very short distance through the metal of the combustion chamber walls, and the heat flow through all these metal parts such as cylinder liners, cylinder covers, pistons, etc., is a steady and constant flow to the cooling medium.

This steady heat flow through the body or bulk of the metal to the cooling system is dependent only upon the amount of heat generated per unit area of surface. In other words for a given engine, the heat lost to the jacket or cooling system is a function of the generated

B.T.U. per hour per square foot.

The temperature of the bulk of the metal is affected by this factor only, while for a given amount of heat transmitted, the cyclic rise of the skin temperature will depend upon the number of cycles or combustions and will be the most, the fewer the combustions, and will be proportional to the generated B.T.U. per injection per square foot of piston area.

If the temperature rise of the skin goes high enough it may cause it to burn by the F e O reaction as mentioned previously.

We have seen that the skin of the metal surface seems to dampen out the cyclic fluctuations of the heat, at any rate the gradient through the metal walls is constant while the skin undergoes considerable rise and fall of temperature; this produces unequal expansion between the bulk and the skin. Thus it is evident that stresses will be set up in the skin and there will be a limit at which these cyclic stresses can be allowed to go before cracking occurs. To clearly show this—

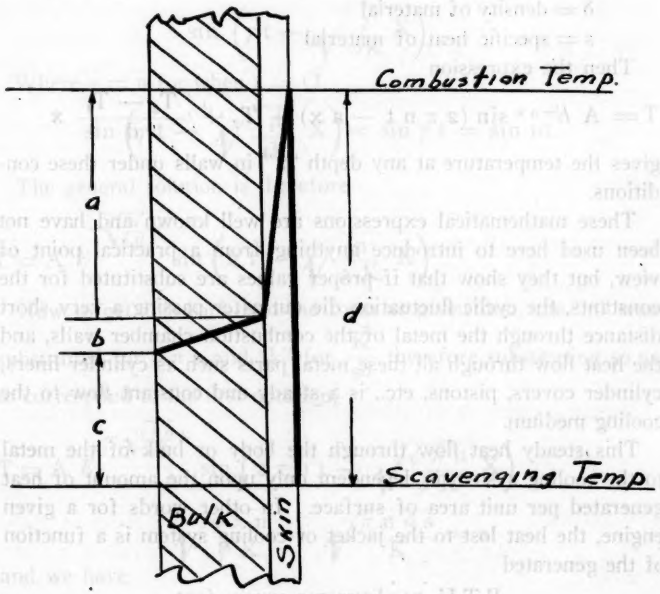


FIG. 3.

Let Figure 3 represent a section of a combustion chamber, with the thickness of the skin surface exaggerated. The cyclic rise and fall of temperature of the skin is represented by (d) and the temperature gradient through the bulk of the wall is shown by "b." "a" represents the temperature rise above this gradient when combustion occurs and "c" shows the fall of temperature below the bulk temperature when scavenging takes place. In this way the skin seems to store up heat at combustion and feed it out during the rest of the stroke. This alternate " storing up" and " feeding out" of the heat at combustion also puts an alternate compression and tension stress on the skin. The limit to which these stresses may rise before cracking of the skin takes place, obviously will be the " elastic limit" of the metal, and this elastic limit is greatly reduced by the high temperatures.

The cracks that are produced in this way may not be serious so long as they are confined only to the skin, but if the heat is such that for a given size of bulk the temperature gradient becomes excessive through it, then these cracks will continue to grow deeper, ultimately causing rupture, because the bulk of the wall has a higher mean temperature at one point than at another.

We may conclude then that for any given size of bulk member, there is a limit at which the heat can be absorbed without cracking.

As the internal combustion engine is primarily a heat engine its efficiency may be increased by minimizing the heat lost from the charge to the cylinder walls, particularly during the first portion of the working stroke. The power of the gases to expand and do useful work depends upon the temperature of these gases and if there are long losses of heat to the cylinder walls during the first part of the stroke, the temperature of the gases will be correspondingly reduced with consequent decrease in power.

The heat lost to the cylinder walls is most serious in lowering efficiency at the beginning of the working stroke and least serious at the end of that stroke. (At the end of the working stroke little more is to be obtained from the gases by expansive work.)

These conditions call for special design to reduce the amount of heat dissipation to the cylinder walls.

Engines of the Diesel type, having large and heavy castings for cylinder heads and employing valves and their operating mechan-

isms, etc., do not lend themselves readily to this special design. With engines of this nature it has called out the best in skill of design to cope with the problem of heat transfer to the cooling fluid.

Many failures of the Diesel engine can be laid at the door of "Poorly designed members subjected to the transmission of heat." Few designers realize the importance of this phase of their work.

It is sometimes said that cooling is necessary to prevent cracking in the piston crown; this is rather doubtful because if cracking is due to temperature gradients through the metal thickness, these are actually steeper with water cooling than without it, the heat flow being greater through a given thickness.

It is roughly estimated that the heat loss by piston cooling is 10 per cent of the total heat supplied to the cylinder. This estimate is probably based on the comparison between the performance of a Diesel and the Still engine—roughly thus—

Fuel consumed by Still engine .36 pound per horsepower per hour.

Fuel consumed by Diesel engine .40 pound per horsepower per hour.

Published data from tests carried out on large Diesel engines gives the actual distribution of temperature across the crown of a water cooled piston as approximately represented in Figure 4:—

Also we know (from "Motorship," Oct., 1921, page 251) that with water circulating at a temperature of 130 degrees F. to 150 degrees F. a temperature gradient of about 80 degrees F. per inch of cast iron thickness is induced in the metal parts in constant contact with the working gas of an internal combustion engine cylinder.

For example in a piston having a crown 4 inches thick, such a gradient gives a temperature of about 480 degrees F. for inner layer of crown and 160 degrees F. for its outer layer in contact with the cooling water, the total gradient being represented on a temperature scale by the line 160 degrees—480 degrees in Figure 4.

Now from "Maxwells' Theory of Heat" it is possible to obtain the isothermic lines of distribution of temperatures for all intermediary layers of metal showing that for the design of piston under consideration all the piston rings are compassed by the

isothermic lines corresponding to 480 degrees and 200 degrees with an average temperature of about 320 degrees. For this piston the limiting conditions are therefore:

(*a*) Temperature gradient through piston crown 80 degrees per inch.

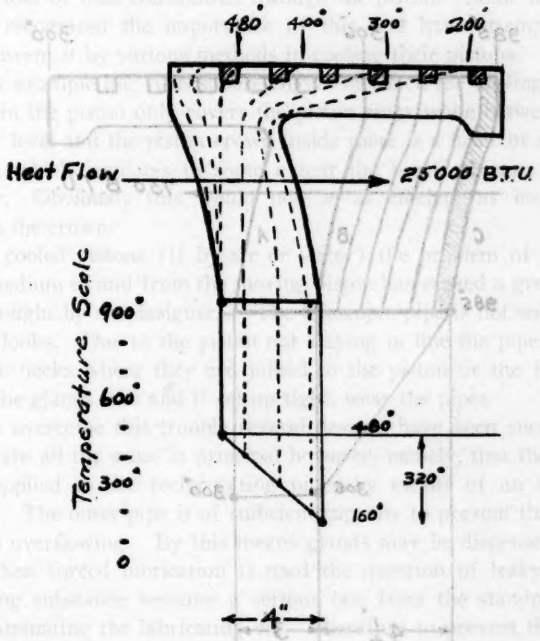


Fig. 4

(*b*) Average temperature of piston rings 320 degrees F.

Now suppose we insulate the crown against radiation and convection of the working gases so that these two conditions are not exceeded, then we have obtained equal or better working without the heat loss intended by piston cooling.

Not carrying out the detailed calculation for this condition the results only will be shown.

In Figure 5 the same piston has been modified in design slightly by decreasing thickness of crown from 4 inches to 3 inches and some form of insulating material secured to the crown by a pro-

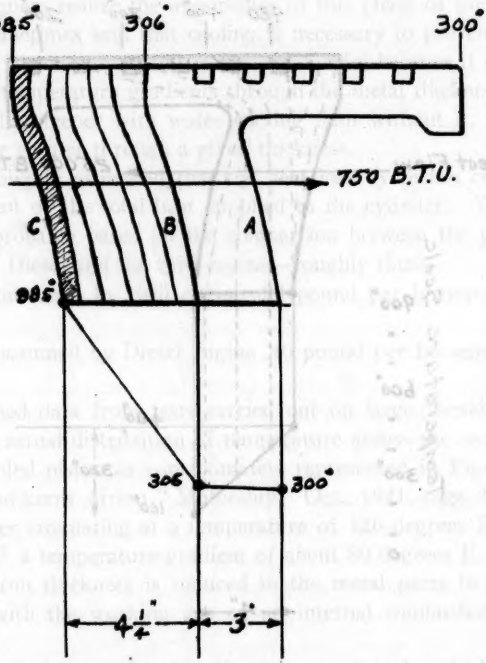


Fig. 5

tecting sheet of wrought iron. The temperature of outer layer "A" can be regulated by thickness of insulating material "C" "B."

From the two Figures 4 and 5 the relative heat flows of the two types of pistons are quite different. In one case 25,000

B.T.U.'s were lost to the cooling water while with the insulated piston only 750 B.T.U. were lost.

From a practical point of view this could hardly be carried out because of the difficulty in insulating the piston as described. But it presents something for thought and pictures a little better the great loss of heat transmitted through the piston. Some builders have recognized the importance of this and have attempted to circumvent it by various methods in cooling their pistons.

For example the Werkspoore engine in which the cooling water level in the piston only covers the piston rings while between this water level and the piston crown inside there is a layer of air and steam which insulates to some extent the heat's passage to the water. Obviously this would not be as efficient as insulating above the crown.

In cooled pistons (if by air or water) the problem of getting the medium to and from the moving piston has caused a great deal of thought by the designers. The telescopic pipe is not so simple as it looks. Due to the piston not staying in line the pipes break at the necks where they are joined to the piston or the framing and the glands leak and if set up tight, wear the pipes.

To overcome this trouble several designs have been successful, they are all the same in principal however, namely, that the water is supplied to the reciprocating pipes by means of an internal pipe. The outer pipe is of sufficient capacity to prevent the water from overflowing. By this means glands may be dispensed with.

When forced lubrication is used the question of leaky piston cooling substance becomes a serious one from the standpoint of contaminating the lubricating oil. Therefore to prevent this contamination by leakage, oil is circulated through the piston instead of water.

Oil has many disadvantages while only the above advantage supports it. Even while the seriousness of this leakage seems momentous it can be reduced by careful design. Cooling the piston with water is purely a design problem and should not cause undue apprehension. With a purifier the leakage is not a serious feature.

Oil as a circulating medium must possess the capacity of taking up or absorbing and transferring heat under high temperature conditions. It must resist oxidation and gumming and must not carbonize readily.

The selection of high quality, straight mineral oil will eliminate the danger of gumming or carbonizing, thereby keeping the pipes, etc., of the circulating system free. An oil of low quality will oxidize and throw down deposits when subjected to rapid circulation at high temperatures, this carbonization will also form deposits or coating on the interior of the piston surface which interferes with the transfer of heat. The life of the oil will be short, and damage to the engine will surely follow.

At its best, oil has a poor capacity for absorbing and giving up heat. The specific heat or thermal capacity of oil is only about half that of water, and its film resistance to heat flow is somewhere in the order of 30 times that of water under same conditions.

If water is used the question of "Fresh or Seawater" comes up and it is surprising to note the diametrically opposite views taken by different Diesel engine manufacturers. Some use fresh and others seawater and the two cases are about equal.

For marine purposes seawater would present a strong argument because it is plentiful and costs nothing. But in many instances the ship must navigate rivers or water that contain muds and other deposits. In this case a closed system would seem the best for all around general purposes. Obviously if freshwater is used it must be a closed system. Naturally the closed system involves additional expenditure which the ship owner may not care to incur when he learns of the numerous vessels now in operation in which open seawater is employed for all purposes.

In a great many of the later engines water is used for piston cooling; they get around the element of chance whereby lubricating oil might be contaminated by leaks by putting all stuffing boxes or joints on the outside of the casing; again the water question is purely a matter of design to make it a successful installation.

AMERICAN AIRCOOLED AIRCRAFT ENGINES.

By Commander Eugene E. Wilson, U. S. N., Member.

From the technical viewpoint, the year 1927 marks the rise to supremacy of American aircooled aircraft engines. The long series of trans-oceanic flights which placed America in the forefront of aeronautics was made possible only through the superiority of our aircooled power plants. This year, then, marks the culmination of a long struggle which began shortly after the close of the World War. The whole development has been fostered by the Navy. The final result can be a matter of pride to all Naval Engineers since it represents the efforts of a considerable number of Naval officers who have had a part in it from the beginning.

Early aircraft engines followed automotive practice and were watercooled. After mechanical flight had been accomplished, no rapid developments took place until the watercooled engine was replaced by the aircooled rotaries. From that moment rapid strides were made. The rotaries, so called because the crankshaft was fixed and the cylinders rotated, had a number of disadvantages. The gyroscopic effect of the rotating mass influenced the airplane's performance. Crank speeds were limited by the fact that above a certain point the fan work limited the engine's output. Centrifugal stresses limited the engines to comparatively low horsepower. When the war broke out higher powers were demanded and the watercooled engine returned to supremacy. At the close of the war attention was focused upon the possibilities of the fixed radial engines whose design was such as to eliminate most of the objections to the rotary. However, by this time, watercooled engines had become highly developed and the new proposal met with little support.

Mr. Charles L. Lawrance, now President of the Wright Aeronautical Corporation, appreciating the inherent advantages of the fixed radial as a type undertook the development in this country. He found ready support in the Navy from the officers in the

Bureau of Engineering who were in charge of power plant development. With the formation of the Bureau of Aeronautics this support was continued. Mr. Lawrance's first engine was the three-cylinder 60 H.P. " L" engine. This power being insufficient for Naval purposes, the logical step was the nine-cylinder radial which began with the " J-1" and has progressed through various designations up to the " J-5C."

The numeral in the designation has been changed with major design changes which affect interchangeability. The final letter has been changed when more detail design changes not involving interchangeability have been indicated. Usually the design changes have taken place between contracts, but in some cases it was necessary to modify the engines during a contract. The Navy Department's contribution to the development was made possible by a well defined procurement program for aircraft. The natural result of this has been continued production of the engines in quantities at an economical rate. The performance of the engines in service, their defects, and recommendations for changes have been reported by the operating squadrons. As a result of these reports, the Bureau has incorporated changes and improvements. The final engine is, then, the result of a cooperative effort.

The details of the Model " J," called commercially the Wright " Whirlwind," have been ably described in this JOURNAL by Captain H. C. Dinger, U. S. N. (November 1926 issue). The modifications made were designed to bring about improved durability, improved dependability, improved fuel economy, and greater ease of maintenance.

Mr. Lawrance carried on the work for the Navy Department first with his company known as the Lawrance Aero Engine Corporation. As it became apparent that improved facilities were required, a consolidation was effected with the Wright Aeronautical Corporation, Paterson, N. J., manufacturers of the famous Hispano-Suiza engines in this country. This brought together the best design information on the subject and superior manufacturing facilities. Mr. F. B. Rentschler was President of the Wright Aeronautical Corporation and Mr. Lawrance became Vice-President. Later when Mr. Rentschler withdrew to form the Pratt & Whitney Aircraft Company, Mr. Lawrance became

President of the Wright Aeronautical Corporation and Mr. Guy W. Vaughan its Vice-President and General Manager.

In order to evaluate the advantages of the aircooled engine it is necessary to lay down a basis of analysis for aircraft engines. Fundamental requirements are: (1) Minimum weight per horsepower, (2) minimum fuel consumption, (3) maximum dependability, (4) maximum durability, (5) maximum ease of maintenance, and (6) minimum cost. It is manifest that the aircooled power plant will weigh less per horsepower than the watercooled plant because the cooling system, which weighs about .7 pound per horsepower, is eliminated. Since our records show that at least one-third of all of the engine failures can be traced to cooling system failures, it is apparent that the aircooled engine is superior from the viewpoint of dependability. Proponents of the watercooled engine were willing to admit the possibilities of these, but pointed out that the aircooled engine had not proved its mechanical dependability nor its durability.

It should also be apparent that the fixed radial type of aircooled engine as contrasted to the Vee type has the superiority from the standpoint of weight per horsepower because it is more compact. Manifestly, too, it should be cheaper to build than the in-line engine because of its simplicity. It should be much more readily maintained because of the accessibility of the parts. Any one cylinder is quickly and easily removed, something which is not true of the in-line engine. From every angle, then, the single row fixed radial aircooled engine is inherently superior to any form of watercooled engine. It was the task of the pioneers to perfect the mechanical design of the radial in order to utilize its inherent advantage.

Against the fixed radial aircooled engine only one disadvantage could be urged. Its frontal area is apparently large. Even this disadvantage disappears when we remember that a fuselage at least large enough to carry a man must be placed behind the engine so that in practice the only additional drag presented by the aircooled engine is that of exposed cylinders. However, the radiator of a watercooled power plant likewise offers drag. As a matter of fact, it takes about the same parasite resistance to cool the engine whether the job be done directly through the cylinder fins

or indirectly through the radiator. In spite of this factor, so apparent on rational analysis, aircooled engines were received with skepticism, if not actual resistance, because of this " frontal area" argument.

Now the factor of weight per horsepower which, of course, takes in economy if we consider the full power plant weight for a given performance, is of vital importance to Naval Aviation. Our aircraft must be of minimum size and weight if they are to be flown from the decks of ships. They must be not inferior in performance to any shore-based aircraft, in spite of certain additional limitations. They must have low landing speeds for both seaplane and carrier operation. If they are not to be inferior in high speed, then they must have a superior speed range. They must accomplish this carrying greater structural weights than shore-based aircraft by the amount of the weight of the carrier arresting gear and reinforcement therefor, as well as the weight of the reinforcement for catapulting. In other words, the employment of Naval aircraft at sea which requires that they be interchangeable from landplane to seaplane and reinforced for deck arresting, as well as catapulting, imposes limitations which must be overcome. The aircooled engine, manifestly, afforded a means of overcoming these handicaps and this formed the basic motive for the Navy's development.

As the aircooled engines were placed in service, greater benefits were realized than had been anticipated. It is a matter of common fact that the cooling system complication with its weight is just enough to make it almost impossible for even the most skilled designers to do a very creditable job around the watercooled engine in anything except the fighter class of aircraft. The elimination of this weight and complication removes an initial requirement for compromise which makes it possible for even the comparatively inexperienced designer to do a most creditable job. Evidence of this is found in the Ryan Monoplane which Lindbergh flew to Paris. When now a most skillful designer begins to work around the aircooled engine, the inevitable result is such a striking achievement as the Vought " Corsair" two-seat observation airplane about the Pratt & Whitney " Wasp" engine, a service airplane which immediately after its service trials took the air with-

out alterations and broke four world's records, one for altitude and three for speed. In other words, the modern aircooled aircraft engine has made our service airplanes record breakers.

It was the appreciation of these possibilities, after careful analysis, which resulted in the Navy's undertaking in conjunction with Mr. Lawrance the development of the Wright "P-1" 400 H.P. fixed radial engine. At the time the "P-1" was undertaken we were inexperienced in the design of the radial. As a result the "P-1" engine did not progress as rapidly as was necessary, and we were forced to continue utilizing the watercooled engines. Naturally, every effort was made to improve and refine the watercooled engine pending the development of the aircooled, and so we found ourselves developing the aircooled engine's competitor right alongside the aircooled engine. This made the path of the aircooled engine more difficult as we went along, but the final result was the more complete.

In the summer of 1925 Mr. F. B. Rentschler organized the Pratt & Whitney Aircraft Company, Hartford, Conn., for the express purpose of accelerating the development of the 400 H.P. engine. Mr. George J. Mead, who had wide experience with the Wright Aeronautical Corporation in the manufacture of the "Whirlwind" engine for that corporation, became Chief Engineer. The Pratt & Whitney Company started out with a clean slate. Mr. Rentschler's experience in the aeronautic world was unexcelled. The facilities of the Pratt & Whitney Company are well known throughout the world. It was to be expected, then, that the final result would be gratifying.

Inasmuch as the aircooled engine found itself up against the most difficult problem in the fighter field, it was decided to attack this problem first. A very careful analysis of the problem in conjunction with Mr. Chance Vought, designer and builder of our shipboard observation airplane, indicated that an engine developing about 400 H.P. on a weight of 650 pounds was the ideal engine for our purposes. In fact, it was Mr. Vought himself who first came to the Bureau with a statement that if he could be given an engine of just those characteristics he could develop a two-seater observation replacement machine for the UO's, small enough to be catapulted from the existing air catapults on the light cruisers,

but having performance comparable to the best single seaters in existence at the time. It was therefore decided to build a fixed radial engine with 1300 cubic inches displacement on a weight not to exceed 650 pounds.

The Pratt & Whitney " Wasp" engine was designed in detail by Mr. George J. Mead in close cooperation with the Bureau on one hand and Mr. Vought on the other. For the first time in our history, the airplane builder and the engine builder cooperated in such details as the method of mounting the engine, the location of the accessories, the form of the engine for best aero-dynamic arrangement, etc. Manifestly, this in itself was a step in advance.

In the meantime, in the detailed design of the engine, every part was analyzed from the standpoints of weight per horsepower, fuel consumption, dependability, durability, cost, and ease of maintenance. The whole assembly was analyzed and re-analyzed from all these standpoints. At the same time, one eye was kept on the future, as it was contemplated that a 1700 cubic inch engine for the heavy duty work, having the same general design, would be constructed. The " Wasp" was therefore designed to permit the maximum interchangeability with the larger " Hornet."

Previous large radial engine had found a limit of about 1800 R.P.M. in crank speeds. This was due to the employment of the split master rod with bolted on bearing cap. In order to remove this limitation, which was a critical one, particularly in the fighting airplanes where engines must be dived at crank speeds of around 2500 to 3000 R.P.M., a radical change was made. The connecting rod was made in the form of a solid forging, Figure 1. The crankshaft previously left solid was split at the rear cheek and the crank pin was threaded through the connecting rod, Figure 2. The crankshaft was designed in detail to render this possible. This was the first important change in design.

Previous crankcases had been of cast aluminum alloy and were, in general, quite complex in their form. In view of the fact that forged duralumin had superior strength-weight characteristics, it was decided to use this material. The simplest form of crankcase was then designed. This is split on the transverse center line of the engine and held by nine through bolts. The front and rear cases are interchangeable and are forged from the same die,

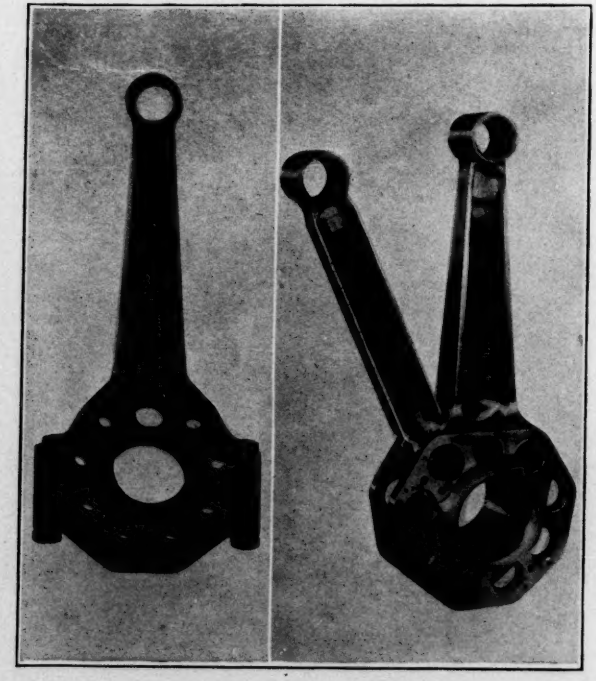


FIG. 1.—PRATT & WHITNEY "WASP" ENGINE.
SOLID AND SPLIT MASTER RODS.

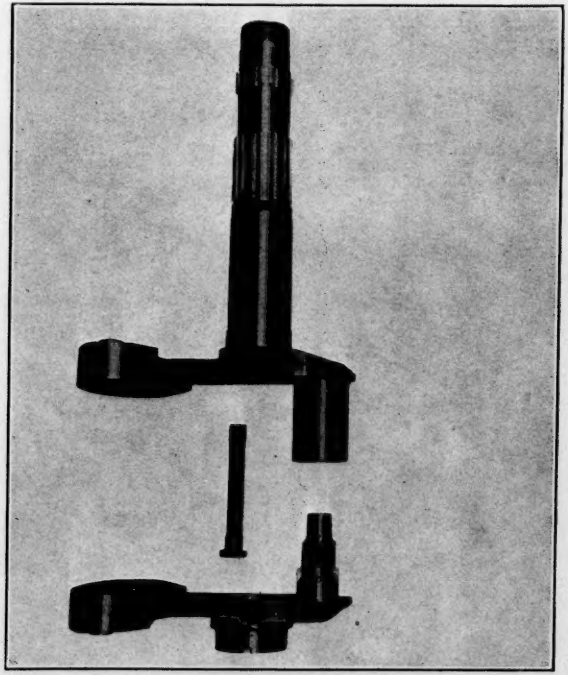


FIG. 2.—PRATT & WHITNEY "WASP" ENGINE.
SPLIT CRANK SHAFT.

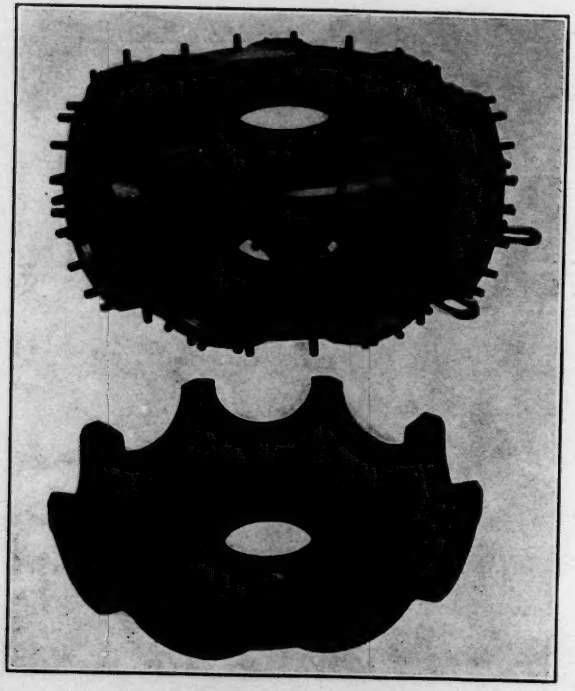


FIG. 3.—PRATT & WHITNEY "WASP" ENGINE.
FORGED DURALUMIN CRANK CASE.

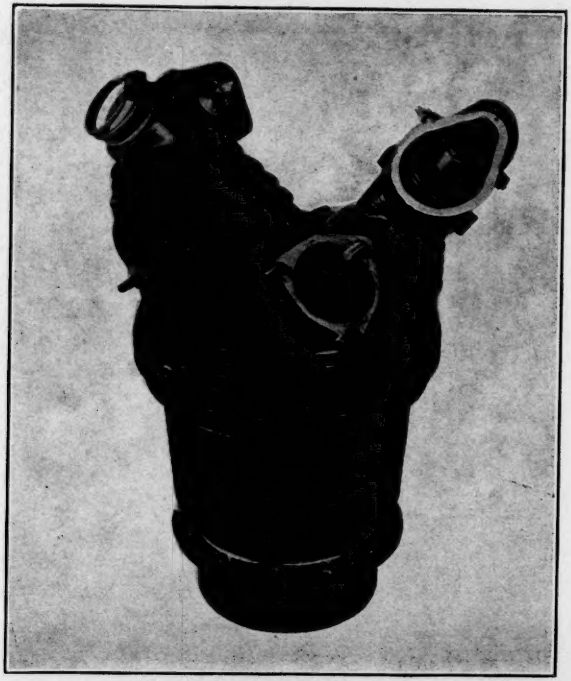


FIG. 4.—PRATT & WHITNEY "WASP" CYLINDER.

FIG. 3.—PRATT & WHITNEY "WASP" ENGINE.
FORGED DURALUMIN CRANK CASE.

FIG. 4.—PRATT & WHITNEY "WASP" CYLINDER.

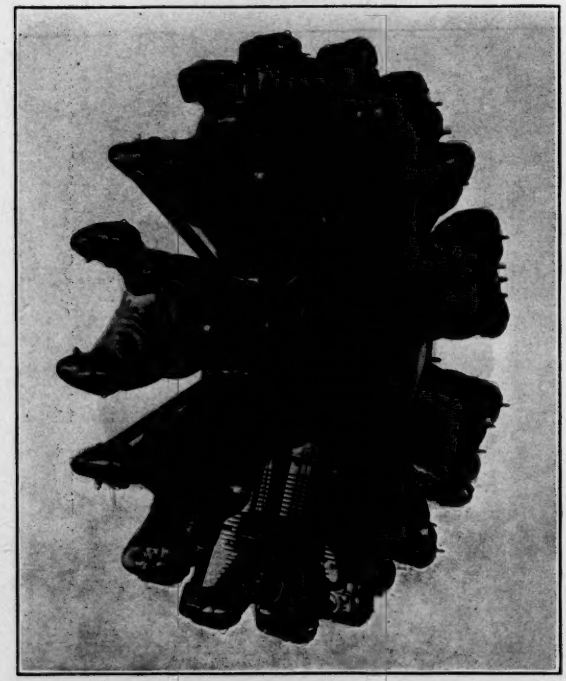


FIG. 5.—PRATT & WHITNEY "WASP" POWER SECTION.

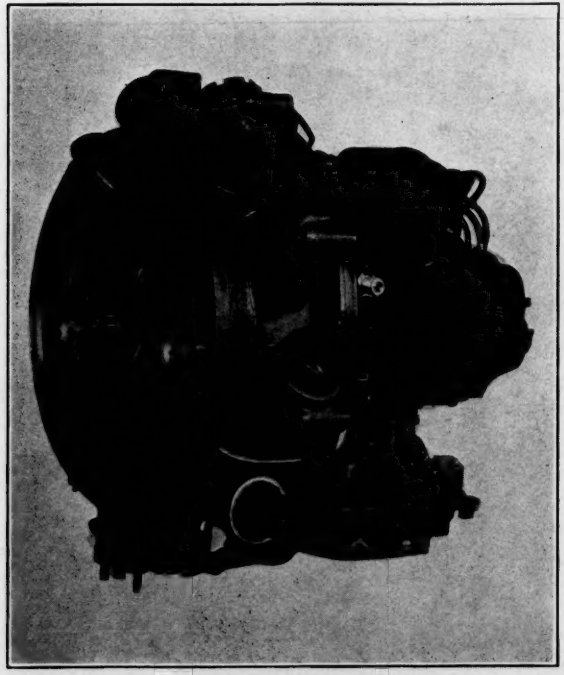


FIG. 6.—PRATT & WHITNEY "WASP" ENGINE
ACCESSORY ASSEMBLING.

Figure 3. The "Hornet" case is the largest known duralumin forging.

The cylinder design, Figure 4, was very carefully worked out. Previous aircooled engines had suffered by comparison with watercooled engines through inferior cylinder cooling. The form of the combustion chamber and the arrangement of the fins was very carefully detailed. A finned steel barrel flanged at the bottom for bolting on to the crankcase carries the cast aluminum cylinder head which is shrunk and screwed on to it. So carefully was the cylinder design worked out that it has proved itself superior to watercooled engines from the standpoint of cooling, with the corresponding improvement in fuel consumption. When the cylinders are holted on to the crankcase, we have what may be called the "power section" of the engine, Figure 5.

The cam for operating the valve gear and its drive are on the front of the engine with a cover plate to form the nose. This cover plate was designed for installation in the airplane and carries four lugs cast on it for securing the cowling. The nose is readily removable while the engine is still in the airplane, and with it all the valve gear. This makes for ease of maintenance in the field.

All of the accessories are mounted on the rear of the engine where they are protected from the weather and are very accessible even when the engine is running. The accessory end, Figure 6, is designed as a unit to be bolted on to the power section and is interchangeable between the 400 H.P. engine and the 525 H.P. engine. The drives are greatly simplified. Provision is made for driving two Scintilla magnetos, a fuel pump, and an oil pump combination. Provision is also made for driving a lighting generator if required, and the engines are arranged to take any of the inertia starters in general use.

Previous radial engines had suffered somewhat in smoothness of operation due to the fact that with but nine cylinders the distribution was not too good. In order to overcome this the usual induction system was abandoned in favor of a rotary induction system. A supercharger fan designed by Dr. Moss, of the General Electric Company, and furnished by that company, is driven by gearing off the crankshaft at a speed of about five times the crank speed. This fan draws the mixture from the carburetor

and delivers it through specially arranged vanes direct to the cylinders.

The gear ratio is designed to overcome the resistance in the induction system without producing any supercharging effect. The agitation of the mixture and the slight temperature rise resulting from the fan work delivers a perfect mixture to the cylinders, with the result that the engines are very smooth. Furthermore, the positive supply of mixture results in surprisingly good acceleration. The rotary induction system forms a part of the accessory unit and the same system, including the carburetor, can be used for the larger engine. Care was taken in designing this system to permit the substitution of higher gear ratios with a view to using the same form for supercharging if designed. Some important experimental work is being done along these lines.

With this general form, it is manifest that weight per horsepower is a minimum. In fact, the "Wasp" engine is now rated at 424 H.P. at 1900 R.P.M. on a dry weight of about 635 pounds, thus exceeding by 25 H.P. the original power on a weight 15 pounds less. From the standpoint of durability and dependability, the engines have already proved themselves in flight service. Hundreds of hours of hard operation have been flown and the indications are that a life between major overhauls of 300 hours should easily be attained. The engines' dependability has been proved even under overload conditions, such as those involved in the breaking of two world's altitude records and three speed records. An idea of the performance can be had from the fact that in establishing a new seaplane record for 100 kilometers, Lieut. S. W. Callaway, U. S. N., in the Vought "Corsair" reached a speed of 147.263 miles per hour as a seaplane with 500 kilograms of dead load, where the observation race at Philadelphia the previous year had been won by a landplane with no dead load at a speed of 141.83 miles per hour.

From the standpoint of ease of maintenance, the engine is far superior to anything previously known. With the engine still in the airplane it is possible to pull the propeller, remove the front section, remove the cylinders, take off the front half of the crankcase, remove the pistons and connecting rods, as well as the crankshaft, and leave the rear end in the airplane. In other

words, not only are the accessories on the rear end accessible, but every part of the engine is readily accessible while still in the airplane.

Manifestly, in an engine design like this, the cost of manufacture is low. The engines are being purchased today at a cost from fifteen to twenty-five per cent below that of watercooled engines of similar power. Once production is well along, this price will be reduced even further. In other words, from the standpoints of weight per horsepower, fuel consumption, dependability, durability, ease of maintenance, and cost, the new Pratt & Whitney "Wasp" is superior to the best watercooled engines known.

From the standpoint of performance, the engine entered the pursuit field and demonstrated immediately that it was equal to or slightly better in high speed at sea level than the best watercooled fighters. In the matter of altitude performance, including climb, ceiling, and speed at altitude, it is definitely superior even in airplanes equipped with the deck arresting gear. In one of the latest battleship fighters equipped with this engine, the high speed as a seaplane at sea level was greater by a mile or two than the high speed of the same airplane as a landplane. We have, then, today, in production battleship seaplane fighters which are superior in speed, climb, and ceiling to watercooled shore-based fighters. The Vought "Corsair," a two-seater with 1277 pounds of useful load is superior in performance at altitude to some of the best watercooled fighters with 500 pounds less useful load.

With the Wright Aeronautical Corporation in production on the "Whirlwind" engine, which is now widely used commercially and is about to be widely used by the Army, and with the Pratt & Whitney Aircraft Company in production on the "Wasp" 425 H.P. type, interest naturally centers in the next development. The Bureau has encouraged both companies to build a large radial of about 1750 cubic inches displacement. The Wright Company has built its "Cyclone," which is about ready to go into the air. The Pratt & Whitney Aircraft Company has built its "Hornet," a larger edition of the "Wasp," and so designed that over 80 per cent of the parts are interchangeable between the "Wasp" and the "Hornet," including the whole rear assembly. The "Cyclones," "Hornets," and "Wasps" are interchangeable

insofar as engine mountings are concerned, and use the same carburetors, starters, fuel pumps, etc. A striking example of what can be expected to result from the use of these engines is indicated by two new aircraft.

The Douglas twin-engined torpedo bombing plane, which will carry the Wright "Cyclone" engine, has the same gross weight with two aircooled engines as the single-engined watercooled bomber carrying one 800 H.P. Packard. It has, however, nearly 20 miles higher speed and half again the service ceiling with the same useful load. In other words, a twin-engined aircooled airplane on the same gross weight as the single-engined watercooled job has a vastly superior performance, with the same useful load.

Even more striking is the new single-engined Martin three-purpose airplane. The aircooled Martin torpedo plane with the 525 H.P. "Hornet" has a gross weight of but two-thirds that of the 800 H.P. watercooled airplane for the same useful load. It has a high speed at least fifteen per cent greater than the watercooled bomber and attains a service ceiling about one-third greater than that of the watercooled airplane. Not only that, but the problem is so simplified with the aircooled installation that fine military characteristics are available. In addition, the new airplane is as light and handy on the controls as a two-seater observation airplane.

To summarize these developments, we may say that for the last seven years, the Navy Department has fostered the development of a line of three aircooled engines, the 800 cubic inch Wright "Whirlwind," the 1300 cubic inch Pratt & Whitney "Wasp," and the 1750 cubic inch Wright "Cyclone" and Pratt & Whitney "Hornet." It has also developed simultaneously new aircraft designed to utilize to the fullest extent the advantages of the aircooled engines. The engines are rapidly going into service commercially. The "Whirlwind" has been extensively used, and the Pratt & Whitney "Wasp" is the power plant selected by the Boeing Air Transport Company for twenty-four mail planes now in service on the Chicago-San Francisco run. These new aircraft engines not only make available all the advantages of aircooled power plants, but do so around the inherently advantageous static radial form with a detailed design carefully thought out to

meet all the requirements. It has been frequently said that the engine is the heart of the airplane. American aeronautics may now be said to be sound at heart. It is difficult to estimate the possibilities of the future, but the trans-oceanic flights of 1927 are not just flashes in the pan. On the contrary, they are hopeful indications of great future developments.

THE NEW HAMILTON-M. A. N., TWO CYCLE, DOUBLE ACTING, MARINE ENGINE.

By Henrik Greger, Member.

1. Introduction.

Although the Diesel Engine cycle was developed more than thirty years ago, its application to larger engines has only recently been made a commercial success. The Diesel Engine in smaller sizes has had a great development both in America as well as abroad and has found a larger and larger field of application due to the high efficiency obtained. It has developed a field with practically no competition from other prime movers. This has been made possible due to the constant increase of available oil supply at low cost throughout the world.

In the larger prime movers, the steam turbine holds a dominating place. Its construction is such that a high rotative speed can be used and full advantage can be taken from the higher steam pressure and higher temperature which has been steadily developed. It, therefore, is apparent that it is most difficult for a larger Diesel Engine to compete with turbines for power stations and the world's thought during the past twenty years has been directed towards perfecting the turbine in the steam plant and condensing equipment to its highest point of efficiency rather than put their efforts into the Diesel Engine. Although the Diesel is inherently economical, it is difficult to place on a commercial competitive basis with the steam turbine.

The situation at sea, however, is entirely different. By far the largest number of ships afloat are of a medium size and medium speed. The propeller efficiency, with a set speed of the ship, practically determines the most economical revolutions for the engines. Although the turbines have made an inroad, benefitting by the high rotative turbine speed and the slow propeller speed taking advantage of a reduction gearing, they have not solved the

General View, Hamilton, M.A.N. Diesel.

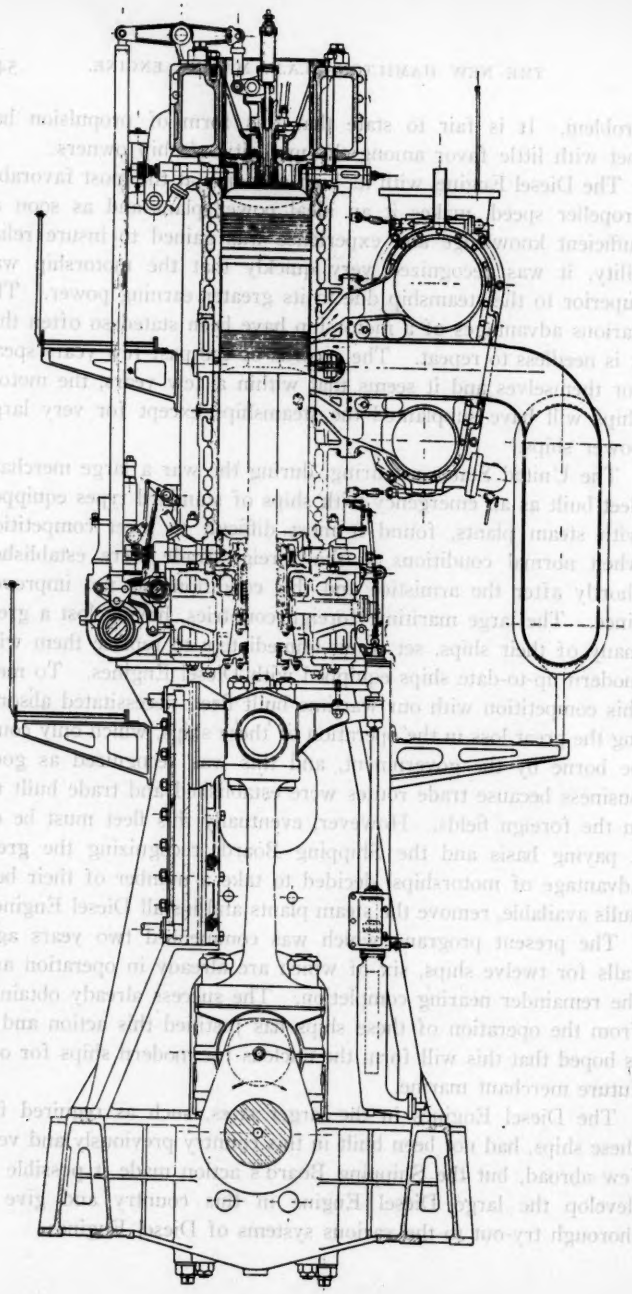
problem. It is fair to state that this form of propulsion has met with little favor among the majority of ship owners.

The Diesel Engine, with its high economy at the most favorable propeller speed, makes it an ideal power plant and as soon as sufficient knowledge and experience was gained to insure reliability, it was recognized very quickly that the motorship was superior to the steamship due to its greater earning power. The various advantages of a motorship have been stated so often that it is needless to repeat. The records of the past few years speak for themselves and it seems that within a few years, the motorships will have supplanted the steamships except for very large power ships.

The United States acquiring, during the war a large merchant fleet built as an emergency with ships of standard types equipped with steam plants, found it most difficult to meet competition when normal conditions in the foreign trade were established shortly after the armistice and this condition has not improved since. The large maritime foreign countries, having lost a great many of their ships, set about immediately to replace them with modern up-to-date ships equipped with Diesel Engines. To meet this competition with our wartime built fleet, necessitated absorbing the great loss in the operation of these ships, which only could be borne by the government, and this was recognized as good business because trade routes were established and trade built up in the foreign fields. However, eventually this fleet must be on a paying basis and the Shipping Board, recognizing the great advantage of motorships, decided to take a number of their best hulls available, remove the steam plants and install Diesel Engines.

The present program, which was commenced two years ago, calls for twelve ships, six of which are already in operation and the remainder nearing completion. The success already obtained from the operation of these ships has justified this action and it is hoped that this will form the nucleus for modern ships for our future merchant marine.

The Diesel Engines in the larger sizes, such as required for these ships, had not been built in this country previously and very few abroad, but the Shipping Board's action made it possible to develop the large Diesel Engine in this country and give a thorough try-out to the various systems of Diesel Engines.



CROSS-SECTION OF WORKING CYLINDER.

In the conversion program are included both single acting and double acting four cycle engines and single acting and double acting two cycle engines.

The Hooven, Owens, Rentschler Company, building under license from the M. A. N. Company of Augsburg, Germany, have recently completed their first engine for the Shipping Board which is a double acting, two cycle engine.

2. DETAILS.

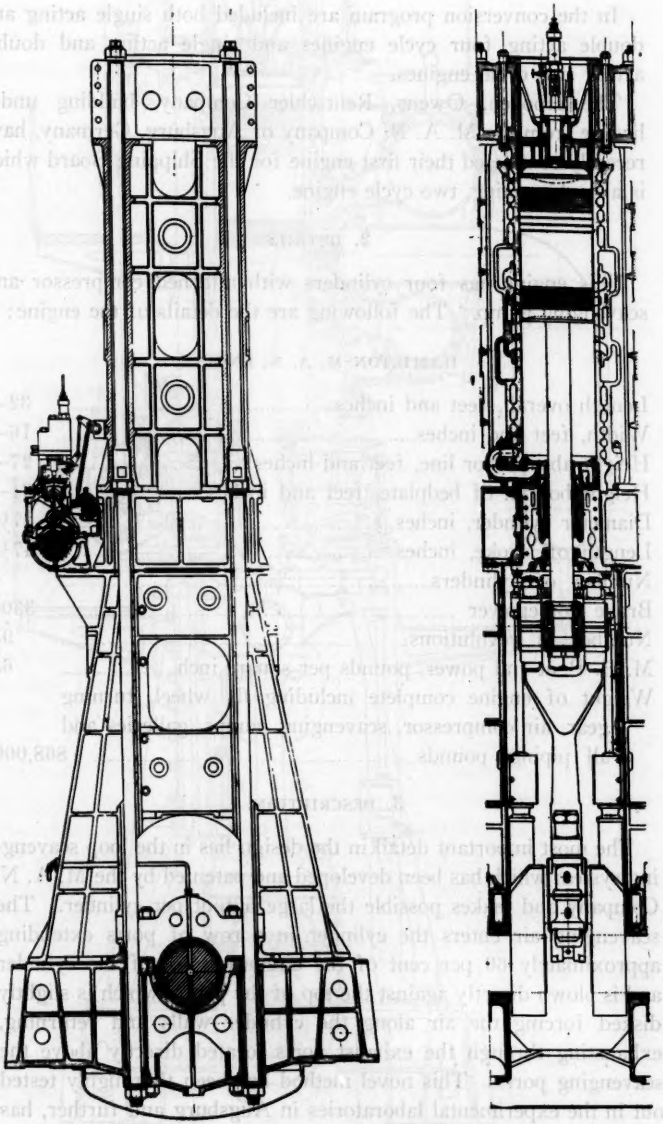
This engine has four cylinders with attached compressor and scavenging pump. The following are the details of the engine:

HAMILTON-M. A. N. ENGINE.

Length overall, feet and inches	32–0
Width, feet and inches	16–0
Height above floor line, feet and inches	27–6
Height bottom of bedplate, feet and inches	31–0
Diameter cylinder, inches	27½
Length of stroke, inches	47¼
Number of cylinders	4
Brake horsepower	3300
Number of revolutions	95
M. E. P. at full power, pounds per square inch	65
Weight of engine complete including fly wheel, turning gear, air compressor, scavenging pumps, galleries and all piping, pounds	868,000

3. DESCRIPTION.

The most important detail in the design lies in the loop scavenging system which has been developed and patented by the M. A. N. Company and makes possible the large output per cylinder. The scavenging air enters the cylinder in a row of ports extending approximately 60 per cent of the circumference of the cylinder and is blown directly against the top of the piston which is slightly disked forcing the air along the cylinder walls and returning, exhausting through the exhaust ports located directly above the scavenging ports. This novel method has been thoroughly tested out in the experimental laboratories in Augsburg and further, has



SECTION THROUGH FRAMING AND WORKING CYLINDER.

been proven in the many engines already placed in operation during the last eighteen months, since the first engine was completed. The upper and lower parts of the cylinder are identical as far as the scavenging arrangement is concerned and the system lends itself very well to the double acting principle due to the simplicity of its construction.

The bedplate is of a conventional design with wide and deep sections so as to give a secure footing. Directly on top of the bedplate are the housings which are independent for each cylinder. On top of the housings are bolted the lower entablatures which are of a heavy cast iron structure extending the entire length of the engine. To the upper face of these entablatures are bolted the cylinder columns which are also independent for each cylinder and to the top of these columns are bolted the upper entablatures of similar construction as the lower except that the entablatures are divided between each cylinder so that each cylinder can be removed independently.

Tie bolts are placed inside the housings and extend from the bottom of the bedplate to the top of the upper entablatures and these are bolted up snug with an initial tension so that the tension load is taken up in these tie bolts, relieving the cast iron structure entirely from any tension strain.

The cylinder and cylinder jackets are independent and set in between the columns between the upper and lower entablatures. The liners for each cylinder are made in two parts, one for the upper and one for the lower, and so set into the cylinder jacket that there is a clearance space in the center allowing for contraction and expansion.

The cylinder jackets are held to the lower entablature through bolts and with a recess for the liner which forces the liner onto a seat on the lower entablature and the upper liner is flanged and bolted to the upper entablature; the cylinder jackets extending on the upper cylinder liner for a sufficient distance to allow water cooling.

The idea of the design is to form a solid construction both lengthwise as well as crosswise for absorbing the stresses. The cylinder heads as well as the cylinder jacket and liners are designed with a view of effectively taking care of all heat and power

stresses. The cylinder heads are made in three parts, the part near the combustion chamber absorbs the heat whereas the combustion pressures are transferred by specially constructed cast steel pressure pieces to the upper and lower entablatures. These pressure pieces are secured to the entablatures by strong flanges. To obtain a rapid circulation of the water, a special piece is set into the cylinder head directing the flow of the water. The lower cylinder head contains the stuffing box and the pressure piece is made in halves so as to facilitate dismantling.

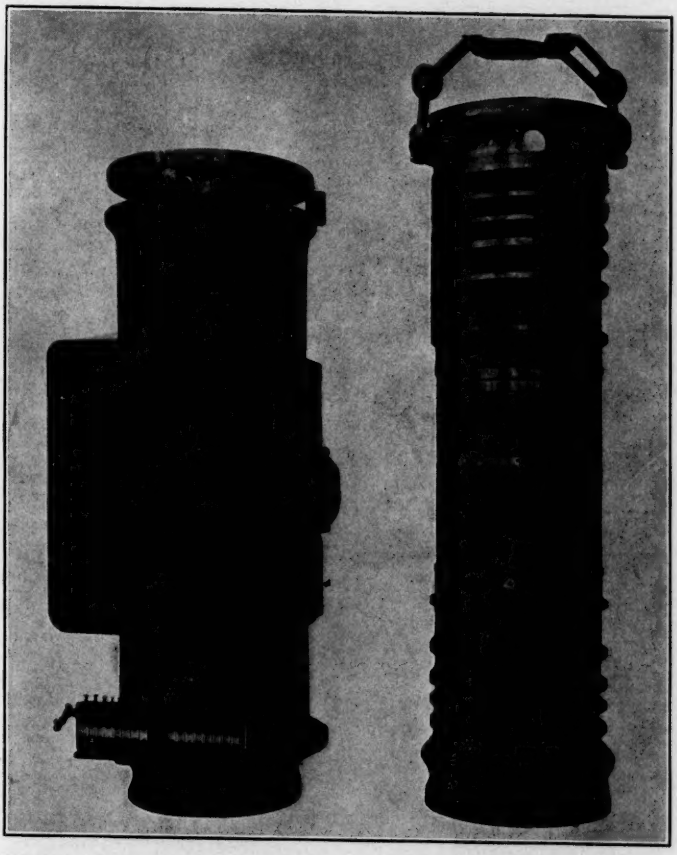
The bedplate is made of cast iron in two parts. The lower part of the bedplate is enclosed for retaining the circulating oil. The main bearings are set into the bedplate with round shells in halves and held by separate caps.

The housings which carry the upper structure are made of cast iron with box section and ribs so as to obtain the greatest rigidity with the least weight. To the housings are bolted the crosshead guides which are also made of cast iron and cored hollow for water circulation. To the guides are bolted the astern guides of steel forging.

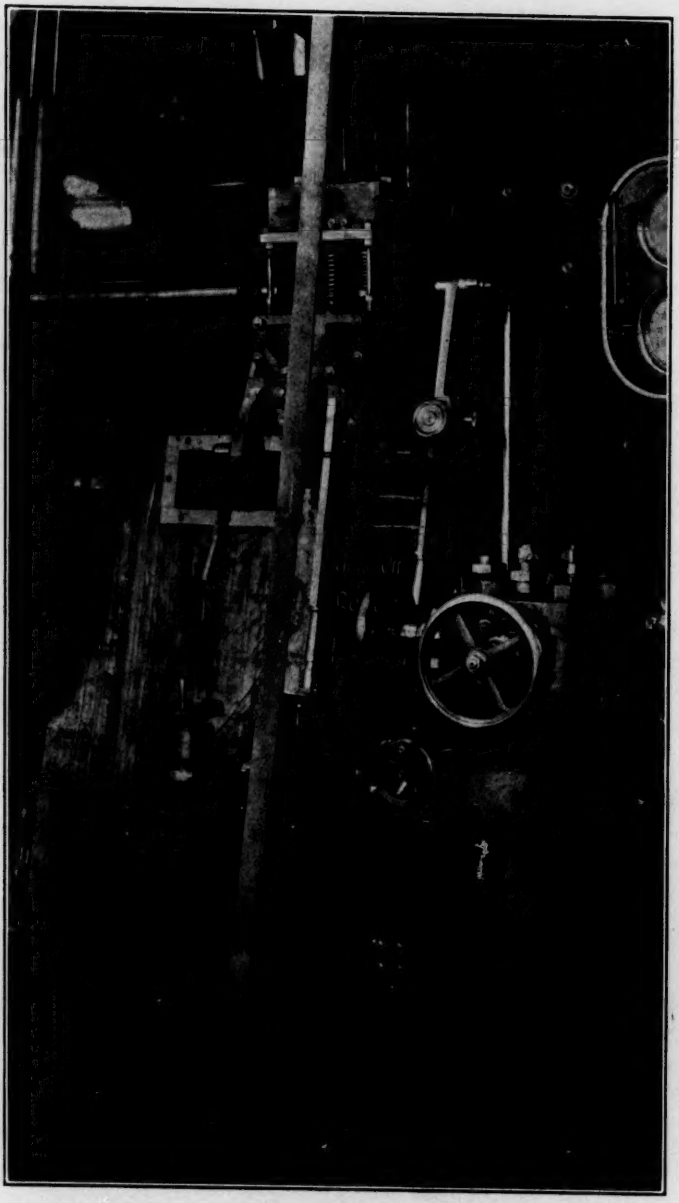
The upper structure, the entablatures and the columns, are of heavy sections of cast iron maintaining the rigidity required so as to eliminate vibration in the engine and insure a steady running. The crankshaft is of the built up type and the parts shrunk together and the shaft is made in two sections bolted together through flanges with body bound bolts. The connecting rod is of the conventional marine type with cast steel boxes for the crank pin as well as the crosshead pins.

The crosshead is made of steel forging to which is bolted the crosshead slipper of steel casting, with babbitted face. The design is known as the single slipper type.

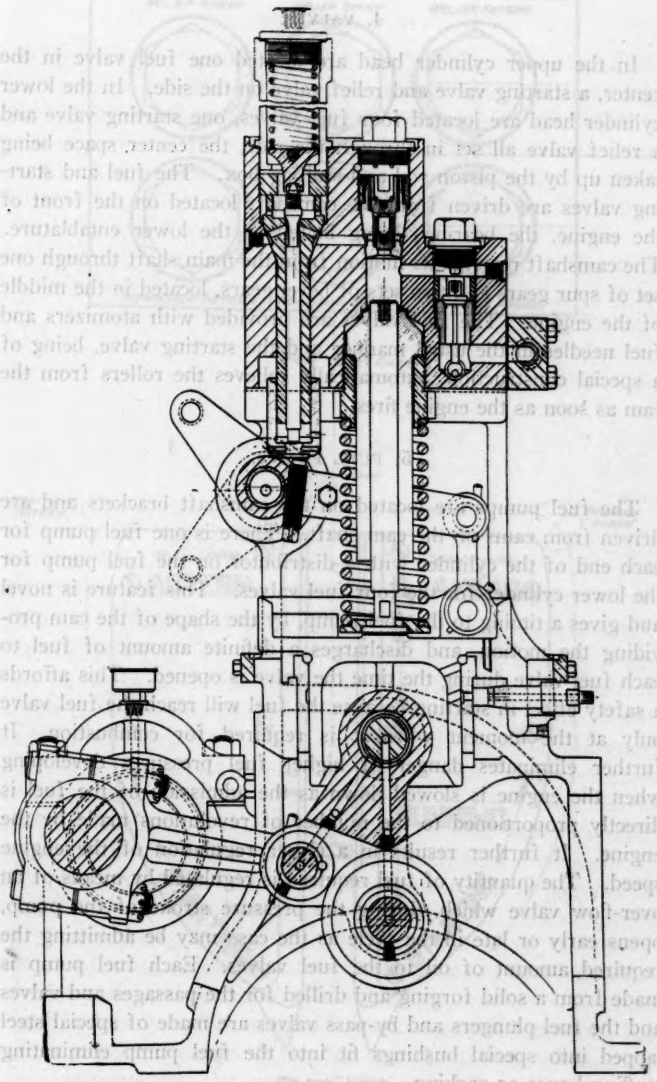
The piston is made of steel casting, one for the upper and one for the lower, the two parts being bolted together to the piston rod. The piston rod is drilled for water circulation; and through connecting pipes, the water is forced to the upper and lower piston heads and passages are so made as to give a rapid circulation and bring the cold water to the hot part of the piston and eliminate possibility for air pockets. The water is carried back through the piston rod separating the space from the inlet through insert tubing.



Working Cylinder and Liner, Showing Method of Joining the Two.



OPERATING STAND.



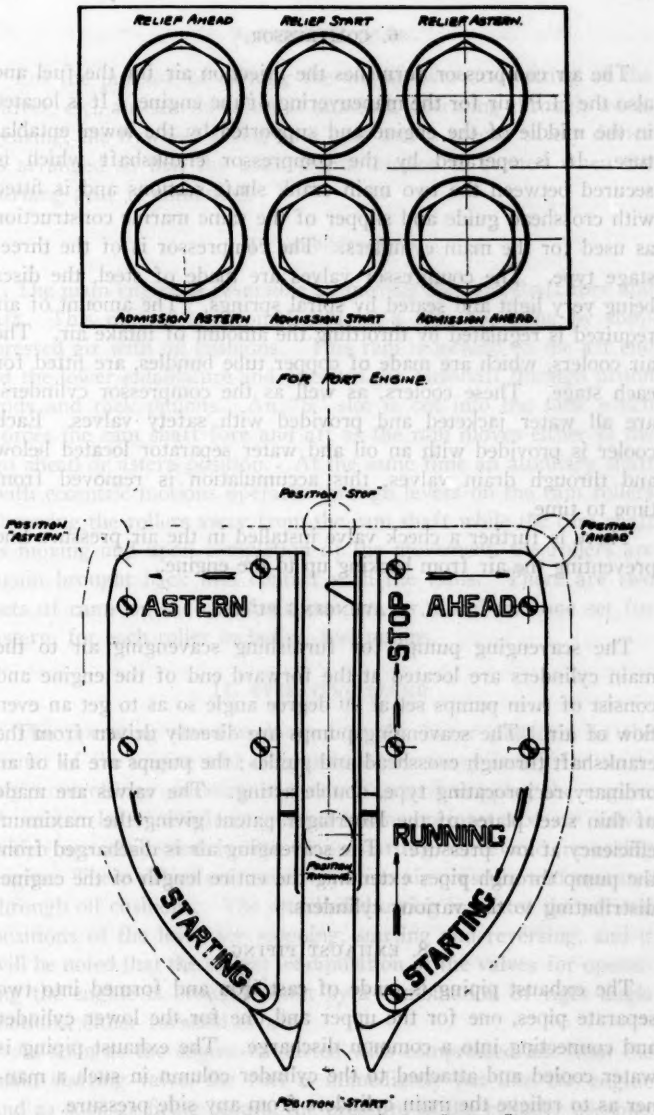
SECTION THROUGH FUEL PUMP.

4. VALVES.

In the upper cylinder head are located one fuel valve in the center, a starting valve and relief valve on the side. In the lower cylinder head are located four fuel valves, one starting valve and a relief valve all set in through the side, the center space being taken up by the piston rod and stuffing box. The fuel and starting valves are driven from the camshaft located on the front of the engine, the bearings being bolted to the lower entablature. The camshaft receives its motion from the main shaft through one set of spur gears and two sets of bevel gears, located in the middle of the engine. The fuel valves are provided with atomizers and fuel needles in the usual manner and the starting valve, being of a special construction, automatically relieves the rollers from the cam as soon as the engine fires.

5. FUEL PUMPS.

The fuel pumps are located on the camshaft brackets and are driven from cams on the cam shaft. There is one fuel pump for each end of the cylinder with a distributor on the fuel pump for the lower cylinder for the four fuel valves. This feature is novel and gives a timing to the fuel pump, by the shape of the cam providing the motion, and discharges a definite amount of fuel to each fuel valve during the time the valve is opened. This affords a safety effect in starting because the fuel will reach the fuel valve only at the moment when it is required for combustion. It further eliminates danger of higher fuel pressures developing when the engine is slowed down as the admission of the fuel is directly proportioned to the number of revolutions made by the engine. It further results in a closer regulation of the engine speed. The quantity of fuel required is regulated by means of an over-flow valve which, during the pressure stroke of the pump, opens early or late in the cycle as the case may be admitting the required amount of oil to the fuel valves. Each fuel pump is made from a solid forging and drilled for the passages and valves and the fuel plungers and by-pass valves are made of special steel lapped into special bushings fit into the fuel pump eliminating stuffing boxes or packing.



TOP VIEW OF MANEUVERING LEVER GUIDE CAM.
ABOVE—PLAN VIEW OF HOUSING FOR AIR VALVES.

6. COMPRESSOR.

The air compressor furnishes the injection air for the fuel and also the H.P. air for the maneuvering of the engine. It is located in the middle of the engine and supported by the lower entablature. It is operated by the compressor crankshaft which is secured between the two main crank shaft sections and is fitted with crosshead guide and slipper of the same marine construction as used for the main cylinders. The compressor is of the three-stage type. The compressor valves are made of steel, the discs being very light and seated by spiral springs. The amount of air required is regulated by throttling the amount of intake air. The air coolers, which are made of copper tube bundles, are fitted for each stage. These coolers, as well as the compressor cylinders, are all water jacketed and provided with safety valves. Each cooler is provided with an oil and water separator located below and through drain valves, this accumulation is removed from time to time.

There is further a check valve installed in the air pressure line preventing the air from backing up to the engine.

7. SCAVENGING PUMP.

The scavenging pumps for furnishing scavenging air to the main cylinders are located at the forward end of the engine and consist of twin pumps set at 90 degree angle so as to get an even flow of air. The scavenging pumps are directly driven from the crankshaft through crosshead and guides; the pumps are all of an ordinary reciprocating type, double acting. The valves are made of thin steel plates of the Hoerbiger patent giving the maximum efficiency at low pressure. The scavenging air is discharged from the pump through pipes extending the entire length of the engine, distributing to the various cylinders.

8. EXHAUST PIPING.

The exhaust piping is made of cast iron and formed into two separate pipes, one for the upper and one for the lower cylinder and connecting into a common discharge. The exhaust piping is water cooled and attached to the cylinder column in such a manner as to relieve the main cylinders from any side pressure.

9. TURNING GEAR.

For the purpose of turning the engine over and setting of the valves, etc., an electric motor is attached, operating through worm gearing, the flywheel acting as a gear and a special safety device is arranged so that the main engine cannot be started when the turning gear is enmeshed.

10. REVERSING.

The main engine is reversible by moving the cam shaft fore and aft. This motion is accomplished by a ram operating by compressed air with oil cushions. This ram is located on the aft end of the lower entablature and operates the camshaft through piston rods and rack pinions. An "S" slot is cut into the rack which forces the cam shaft fore and aft as the ram moves either in the go ahead or astern position. At the same time an auxiliary shaft with eccentric motions operates through levers on the cam rollers throwing the rollers away from the cam shaft while the cam shaft is moving and upon completion of the movement, the rollers are again brought back into contact with the cams. There are two sets of cams on the camshaft, one set for ahead and one set for astern, for each roller including fuel pumps.

11. OPERATING STAND.

The operating stand is located at the lower platform in the center of the engine and comprises all necessary levers for starting, controlling, operating, maneuvering and stopping the engine. A center lever which is guided below operates six air valves which are connected to the main starting valve and reversing engine. These valves are under injection air pressure and operates through oil cushions. The attached drawing indicates the various positions of the lever for stopping, starting and reversing, and it will be noted that the proper manipulation of the valves for operating the engine is brought about by a combination of right angle motions, either forward or aft.

As soon as the engine is started with compressed air from the main starting valve, the fuel is immediately put into the engine and as soon as firing occurs, the pressure in the cylinder becomes

greater than the pressure of the starting air and the starting air on each cylinder is automatically closed and the cams released from the camshaft. The operating mechanism is provided with locking devices in order that the engine cannot be manipulated in such a way as to do any danger to the engine. For instance, the engine cannot start until the position of the camshaft is definitely in position for either going ahead or going astern.

At the left side of the operating stand are located the air regulating valves which control the amount of air admitted into the compressor and the desired amount of injection air pressure can, therefore, always be regulated by hand manipulation. On the right hand side of the main operating lever is located the lever for regulating the fuel supply. This lever operates directly on the by-pass valve on the pump and the speed of the engine is thus regulated by hand adjustment. To protect the engine against over-speed, an Aspinall governor is attached and operates on the by-pass valve and by cutting in and out prevents the engine from racing, maintaining very close regulation of the engine.

Below the fuel throttle valve is located the injection air regulating valve, which, through a reducing valve, regulates the injection air pressure at any desired pressure below the pressure in the injection air bottle. Through a plunger arrangement in this valve, the fuel is shut off and at the same time the injection air pressure is shut off when the engine is stopped.

On the opposite end from the injection air regulating valve on the operating platform, is located the distributing valve for the air. All the air from the main compressor as well as auxiliary compressor is brought into this valve and distributed from this valve either to the injection air bottles or the starting air bottles.

The entire operating stand is extremely simple containing all the necessary devices for operating the engine safely and efficiently without any complications and entirely safeguarding the engine against mistaken manual operations.

12. LUBRICATION.

The main working parts of the engine are enclosed by the housings with guard plating and protective plates above and with stuffing boxes through which the various rods extend. The crank-

shaft, connecting rod, crossheads, etc., are all drilled and oil is forced in through the main bearings in through the crankshaft and distributed through the various bearings.

The oil is collected in the bottom of the bedplate and carried into a sump tank from where it is pumped by independent driven pump through oil coolers, filters, etc., and circulates through the engine, the entire arrangement forming a closed system and the oil is used over again. The oil pressure maintained in the system is from 20 pounds to 30 pounds.

The gearing for driving the cam shaft is also subjected to the forced system, pipes being lead directly on the contact of the teeth. Only the small pins and bearings for operating valve gear are subject to hand lubrication.

The main cylinders are lubricated by mechanical lubricators. The oil is lead directly into the cylinder liners. There are eight feeds on the circumference for each upper and lower cylinder and the location and the timing of the lubrication is so arranged that the oil is delivered between the piston rings, gaining the greatest efficiency from the oil. The air compressor and scavenging pumps and pistons are also oiled from mechanical lubricators and forced directly into the cylinder at the proper place with regard to the piston rings.

Due to the high temperatures involved, carefully selected oils for the particular purposes must be used in order to obtain the greatest efficiency.

13. WATER COOLING.

The cooling of the parts subject to heat is most important and a proper cooling system is essential to successfully operate the engine and for protecting the materials against destructive heat strains. The cooling system for the pistons is separate from that for the cylinders. The piston cooling is done by fresh water, the water being led into the pistons through telescopic piping attached to the crosshead and the water is led in through the piston rod to the upper and lower pistons and circulated back to the piston rod through an angular space in the piston rod formed by an insert pipe. The proper air chambers are provided in the telescopic piping and special packing is provided.

It is necessary to prevent any water from the piston cooling entering the crank case mulsifying the oil. The cylinder cooling is with salt water and the water is led into the lower cylinder head and then through the cylinder jacket and similarly to the upper cylinder head. Branch connections are made to the compressor and exhaust piping. The entire system is worked out so as to give proper speed and direction to effect the most efficient cooling. The water pressures on the piston cooling are from 25 to 30 pounds and for the cylinder cooling 20 to 25 pounds. The outlet temperatures of the piston cooling are from 100 degrees to 120 degrees F. and for the cylinder cooling from 120 to 140 degrees F.

14. TESTS.

This engine was built for the installation in the Shipping Board ship *Seminole,* this ship being converted from steam to Diesel drive. Before leaving the shops of the Hooven, Owens, Rentschler Company, the engine was subjected to exhaustive tests at various loads, in an endurance test of thirty days. These tests were made under the supervision of the Shipping Board officials and as soon as the test data is collected, it will be published in detail. The details of the ship in which the engine is being installed are as follows:

DETAILS OF M. S. "SEMINOLE."

Gross register, tons	5984
Net register, tons	3847
Length overall, feet and inches	416–0
Beam, moulded, feet and inches	54–0
Depth, moulded to main deck, feet and inches	33–9
Displacement loaded (approximately), tons	13,000
Mean draft, feet and inches	26–10¾
Block coefficiency	.801
Brake horsepower, main engine	3300
Loaded sea speed (approximately), knots	12
Deadweight capacity (approximately), tons	9400

This new double acting engine has already won great favor abroad. The first ship, the *Magdeburg* of 9400 tons was built by the Blohm-Voss and fitted with a six cylinder engine. This ship

is owned by the German-Australian Line and was put in operation in December, 1925. It has made several trips to the Far East with uninterrupted success.

The *Ramses,* a 12,000 ton ship belonging to the same company was placed in service in June, 1926, and has had an equal successful career so far.

The Italian firm, Cantieri Officine Savoia Cornigliano Ligure is building the largest motor passenger ship to date, named *Augustus,* which was launched in December and which will be propelled by four 6-cylinder engines of the M. A. N. double acting type, each developing 7000 H.P., making a total of 28,000 H.P., and operating at 125 R.P.M., the M.E.P. being 68.25 pounds with a piston speed of 984.25 feet per minute.

The above ships have been watched in great detail by the large shipping companies and the many orders which have been placed recently indicate the confidence placed in this engine. At the present time engines are under construction in England by the Vickers Comapny, by the Maatschappij Fijenoord in Holland, and by the M. A. N. Company and the various licensees of the M. A. N. Company in Germany, which consist of the larger shipyards all of which have secured contracts for a number of ships. The new tankers being built by Russia will be equipped with this type of engine. In all there is considerably over 100,000 horsepower under construction at this time. That still larger powers can be reached is evidenced in the 15,000 H.P. engine which was built by the Blohm and Voss for the Hamburg Electric Light Station. This engine has nine cylinders with a diameter of 34 inches and a stroke of 60 inches. This unit has been in operation for a year.

The weight and space occupied by this type of engine makes it possible to utilize it, not only for cargo ships and medium sized passenger ships, but it forms a competitor for powers in larger passenger ships and no doubt this engine will find its place in naval ships as well.

THE ENGINEERING COMPETITION.
SOME CRITICISMS AND A SUGGESTED REMEDY.

By Commander H. T. Smith, U. S. Navy, Member.

It is axiomatic that every system is susceptible of criticism and also of improvement. Taking license from the former and with some hope for the latter, this article is offered.

It is possible under the rules for a ship to have a considerable part of her main propelling plant out of commission due to serious derangement—to acquire this derangement without penalty and to steam for a protracted period in that condition with a comparatively unimpaired score. Such a ship is evidently of little utility to the fleet yet her "Engineering Performance" does not indicate it. This condition arises from having the standard of performance the ability of a ship to perform her immediate mission and from having almost the entire rating of the engineering plant depend on its fuel economy.

Engineering merit should not be in the nature of a laboratory figure, but should be a measure of Engineering efficiency as an element of the military value of a ship.

The standard of Engineering efficiency should be higher than the immediate mission of the ship or plant.

Fuel economy, per se, should have its place but should not dominate Engineering merit.

Engineering reliability and availability should have greatly increased weight.

Material economy should be included in Engineering merit.

The condition of a ship requiring extensive repairs should be indicated by a more greatly reduced merit.

The condition of a ship following a vital casualty should also be indicated by a more greatly reduced merit.

Equitable fuel allowances though extremely difficult if not impossible to obtain, practically determine "efficiency" in the present competition.

Markedly inequitable allowances obtaining during the first two or three years of a ship's commission—the period of adjustment of allowances—tend to involve unfairness and therefore to destroy competitive spirit and morale.

Important alterations undertaken for economy without the Bureau's knowledge or approval usually turn out to be artificial and impracticable.

Methods employed which are artificial would not serve in war time.

Health and comfort and habitability are sometimes sacrificed in strenuous fuel competition, even though the Rules distinctly frown upon this practice.

The records and paper work required are somewhat out of proportion to the thing involved, particularly on small ships where there is but one officer in the Engineer Department.

Fuel savings for competition's sake may entail incidental expenditures, infinitely more in amount, in repairs, maintenance or depreciation of plant.

Personnel are inclined towards less economical operating combinations which, due to differences in allowances, will produce better scores.

Personnel are forced to devote energy on the Rules and H sheet to the neglect, more or less, of the Bureau manual and other sources of good Engineering practice.

Competitive enthusiasm may so work on the human element as to permit some pure mathematics to creep into the H sheet.

A flexibility of conscience may be suffered in respect to penalties due to this same enthusiasm and to the small element of option in the Rules.

In summary, is it not a mistake to assume the standard of condition the ability of a ship to perform her immediate mission rather than her designed mission; to assume the standard of economy on a fuel basis rather than on all expenditures against Engineering; and do not these standards offer a tendency to irregularities and put a false light on the real efficiency and efficacy of an Engineering plant?

To determine whether these criticisms are "fancied or real" is believed to be worth service consideration. Believing that

improvement in the Rules is possible along the lines of increased weight to reliability and availability and also in the addition of a factor for material economy, the following suggestions are offered:

Base Engineering efficiency equally on two fundamental conditions, reliability and economy. That is, first—ability to duplicate designed performance and, second—maintenance and operation in all respects with economy. Expressed in figures this arrangement is:

Reliability	50 per cent
Economy	50 per cent

Economy of operation should be separated into its two natural divisions, namely: fuel economy and material economy. In outline the plan then becomes:

Reliability	50 per cent
Fuel economy	25 per cent
Material economy	25 per cent

The problem of measuring each of these three conditions which would go to make up engineering merit is not difficult. In general, this may be done: for reliability and availability—by the application of a suitable penalty for every casualty or derangement, and for failure to make required full power and endurance trials; for fuel economy—by the same system which makes up the bulk of the present competition; and for material economy—by a record of expenditures against engineering appropriations for repairs and maintenance.

Ability to operate at full power and freedom from casualties and derangements are a direct measure of the competence of a plant with respect to its designed mission. Every casualty to main propelling plant and its dependent auxiliaries, to the main electric plant and its important applications, to the steering gear, to the fire control, in short, to every piece of equipment under the cognizance of the Engineer Officer which is vital to the utmost employment of the ship in action, should be penalized. There should be no element of option in respect to penalties. Furthermore, the penalty should bear some relation to the magnitude of the derangement. For this purpose a unit penalty should be applied when the casualty occurs and should be additive, say a unit

a day, for each subsequent day during which the derangement exists. The time spent at Navy Yards on regular overhaul should not be included as subject to penalty nor should the periods at anchor where the overhaul is for "maintenance" and not for "repair" following penalized casualty. The time at Navy Yard specifically assigned for emergency repairs following penalized casualty should apply.

Fuel economy should be ascertained generally as obtains under the present rules and as shown by the "score." The methods should, however, be simplified. The reduced weight of fuel economy would justify less finesse in itemizing the fuel account.

Material economy should be ascertained from the records of the Bureau in expenditures by quarterly and special allotments afloat plus expenditures in engineering repairs at Navy Yards.

In the spring of 1925, eight or nine sister ships assembled in Hawaiian waters prior to a cruise to Australia. Two of these ships had stripped turbines and another had some other constitutional trouble; all three were eliminated from consideration for an extended cruise except in Navy Yards. One of the five ships which made the cruise was in all respects ready for extended cruising and had been during the entire competition year. She made the cruise efficiently, economically and without penalty of any sort. Arriving home for Navy Yard overhaul—after a year's operations—the engineering plant was in such condition that no requests for Navy Yard repairs were necessary. Yet she stood a very poor last in the Engineering competition of her class.

The plan outlined might obviate such a misleading condition, improve the morale of the large majority of Engineering personnel, and, in the event of war, permit the competition merit to bear a closer relation to each vessel's readiness for active service.

NOTES.

NOTES ON NAVY STANDARD BOILER COMPOUND.

PREPARED BY THE ENGINEERING EXPERIMENT STATION, ANNAPOLIS, MD.

DESCRIPTION, PURPOSE, AND COMPOSITION.

Navy Standard Boiler Compound has been developed as the result of experiments and investigation conducted by the Engineering Experiment Station and by extended experience on Naval vessels.

It is made up of the following ingredients:

76 per cent Na_2CO_3, Soda Ash.
10 per cent $Na_3PO_4 \cdot 12H_2O$, Tri Sodium Phosphate.
2 per cent Tannin.
1 per cent Starch.
11 per cent Moisture.

This compound is purchased from chemical contractors, who make it and pack it in accordance with Naval requirements.

The composition, method of testing, etc., of boiler compounds for Naval use, is given in detail in Navy Department leaflet specifications 1303c issued 1 March, 1923. The wide use of this compound and its well-known composition make it readily obtainable at a very reasonable price. It differs from the usual commercial boiler compounds in that it contains only a small amount of inert water, whereas commercial boiler compounds will often contain as much as 60 per cent of water.

The problem of treating feed water for Marine boilers is somewhat different from that encountered in connection with shore boilers. Hard water is usually not encountered. In Marine boilers, the make-up feed is either distilled or secured from shore supplies where the water is usually fairly soft. In the Navy, distilled water is used almost exclusively.

The problem of treatment is somewhat different where make-up feed is distilled than where make-up feed is taken from shore.

The use of distilled water is advisable except where the shore water is definitely known to be quite suitable. In the case of distilled make-up, the water treatment should take into account (1) a certain amount of salt leakage, (2) the presence of some lubricating oil in the boiler water, (3) the presence of air in the boiler water, and (4) the presence of other dissolved gases which may cause a certain amount of corrosion.

This situation requires that the feed water treatment have—

(*a*) A proper amount of suitable alkali to neutralize any acid contained in the feed or any produced in the boiler due to decomposition of any salts. A moderate excess of alkali to take care of any sudden increase in acid due to extra salt leakage or otherwise.

(*b*) Some suitable material that will counteract the tendency to prime or foam, due to oil and finely divided dirt in the boiler or due to excess alkali sodium salts.

(*c*) Some suitable material that will cause the boiler water to hold the oil and other finely divided solid matter in suspension and prevent it from becoming deposited on the heating surface.

(*d*) Some anti-corrosion material that will, by film deposit or otherwise, protect the metal from local corrosive action.

(*e*) Some material that will counteract the formation of scale from the salts and other impurities holding them in suspension, or which will tend to disintegrate the scale formation after it forms and enable it to be blown out of the boiler.

CHARACTER AND PURPOSE OF VARIOUS INGREDIENTS.

Soda Ash, Na_2CO_3. This is used in powdered or flake form. Its purpose is to produce alkalinity, thus neutralizing any acids that may be present in the boiler water, or which may be formed in the boiler during the process of boiling, from the decomposition of salts in the water. It also acts to break up the scale-forming salts and its presence in excess is desired to create a certain margin of alkalinity to allow for any increase in salt leakage or additional acidity from any cause. A certain excess of alkalinity is also desired to render the water as non-corrosive as practicable.

Soda Ash will act upon calcium sulphate, calcium chloride, calcium nitrate, magnesium sulphate, magnesium chloride, sulphuric or any strong acid. It is the main ingredient of Navy Boiler Compound and of itself has many of the most essential properties of a proper boiler compound for Marine Boilers.

It is used in preference to other alkalis on account of its cheapness, availability, ease of storage, and general immunity from deterioration. It is easily handled and causes no injury to the human skin nor to the materials with which it may come in contact.

Tri-Sodium Phosphate, $Na_3PO_4 . 12H_2O$. This, also, is used in powder form. The purpose of this is to lessen the surface tension of the alkaline water and thus check foaming and priming to a certain extent. It also is an alkali and has certain anti-scale forming and cleaning ability. It will tend to remove any hardness in the water which may be experienced when certain shore waters are used. When boiler water is dirty, due to oil or other suspended matter, a larger amount of tri-sodium phosphate will tend to reduce the tendency to prime.

Tri-sodium phosphate also acts upon calcium sulphate, magnesium sulphate and magnesium chloride. Because it is considerably more expensive than soda ash, it is not used primarily for its action as an alkali, but because of its cleaning action. The amount of this material in Navy Boiler Compound is that judged to be sufficient for ordinary average conditions in Naval boilers. Where the boiler water is unusually clean, more than really necessary would be present, but in that case it acts as an alkali and thus tends to reduce the amount of compound required to maintain the required alkalinity. Tri-sodium phosphate is readily available, and in case there is a tendency to prime, it might be added in somewhat larger proportions, to check this tendency. However, this should not be done 'til after carrying a lower alkalinity has been tried, and should not be necessary if proper precautions are taken.

Tannin. The purpose of this is to introduce a certain colloidal effect, which will hold scale-forming ingredients in suspension and tend to prevent them from depositing. It introduces a certain amount of cleansing ability, deters the formation of scale and assists in the removal of scale where it may be formed.

Tannates also are understood to have a beneficial effect in combining with dissolved gases.

Tannin can be derived from Cutch, which contains about 40 to 45 per cent of tannic acid. The usual source of tannin is hemlock, oak, and chestnut barks and is obtained commercially.

Tannin exists in boiler scale as sodium tannate. It has a slight solvent action on boiler scale and is a solvent for iron oxide. It is not a solvent for metallic iron. Freshly prepared sodium tannate combines with the oxygen dissolved in boiler feed water. Its main action in boiler compound appears to be in the nature of an astringent and as a preventive of precipitated matter in the boiler feed water from adhering to the tubes.

Starch and Dextrine. The purpose of this is to add a certain cleansing and scale removal tendency. These ingredients particularly act upon oil deposits and tend to keep these off the heating surface and in solution. They probably have a certain colloidal effect, but practically they assist in the cleaning and prevention of oil deposit on the heating surfaces. The effects of tannin, starch and dextrine have been found by practical tests and experience. The action on scale or oil deposit is probably more of a mechanical than a chemical action. The principal action of starch in boiler feed water appears to be in the nature of a colloid in that it tends to prevent the deposition of precipitated matter in the water and retain the precipitated matter in suspension so that it may be readily blown from the boiler.

GENERAL ACTION AND LIMITATIONS.

Navy Boiler Compound ensures an alkaline solution, which prevents the presence of free acid, prevents the formation of scale from scale-forming constituents in sea water, should the feed water become contaminated, and prevents the electrolytic action from presence of small amounts of salt. It does not prevent a certain amount of general corrosion due to action of air or other dissolved gases in the feed water. It also acts to keep mineral oil from collecting on the heating surfaces and will reduce or check the formation of scale due to the salts in the water. Boiler compound does not prevent corrosion fatigue and hence corrosion cracks grooving, channeling and other similar action, which are caused by the metal being stressed beyond the fatigue limit are not prevented by its use.

This compound is cheap and the rules for its use are simple. It can be applied without any elaborate tests or analysis. It is supplied in uniform quality and strength. Complete directions for the use of Navy Standard Boiler Compound for average conditions in Naval boilers are given in Engineering Manual—Chapter II, Boilers, and Chapter VI, Feed Water. It can also be used as outlined in Sterling's Marine Engineering Hand Book,—Page 466. Navy Boiler Compound is used to a considerable extent in the Merchant service. It can be used advantageously on shore boilers where the feed water conditions are similar to that in Marine boilers; but where feed water is hard or where it contains different salts or other foreign matter, the formula may have to be modified, and, under certain conditions, a different treatment may be advisable. In some cases, it can be used in conjunction with pre-treatment and external softening apparatus. Its use is not recommended unless analysis of feed water and operating conditions indicate that it can be properly applied.

OTHER MATERIALS FOR BOILER COMPOUNDS OR FEED WATER TREATMENT.

There are numerous other materials that may be used for feed water treatment and some of these may, on occasion, be used in connection with Navy Boiler Compound. The following are mentioned with a brief description of their possible use:

Silicate of Soda (Water Glass).
Sodium Bichromate.
Caustic Soda.

Lime.
Sal Soda.
Kerosene.
Cutch.
Flaxseed.
Miscellaneous materials to secure collodial effect.

Sodium Silicate, $Na_2Si_3O_8$ (Water Glass). This will act upon calcium sulphate, magnesium sulphate, magnesium chloride, and most acids. It is an alkali; however, its use in boiler compounds is for other reasons. It has the property of forming a protective film over metal surfaces and the further. property of preventing scale formation from sea water. It also has the property of securing quicker precipitation of the insoluble salts.

Under certain conditions, sodium silicate will form a protective eggshell scale; hence, a limited amount of sodium silicate may be desirable in such cases where there are extensive salt leaks and where active corrosion appears to be going on. It will tend to prevent salt scale from sea water and also form a protective film for the metal. Sodium silicate will act in particular to check corrosion of steel feed piping and economizer tubes in cases where the water contains considerable air or dissolved gases. It, however, has a drawback in accelerating priming in salty water. It, therefore, must be used with discretion.

Sodium Bichromate, $Na_2Cr_2O_7$ This has a somewhat similar action to Silicate of Soda and can be introduced at times as a special material to arrest any decided corrosive action that may be noticed. It can be secured in briquette form in combination with sodium silicate.

Caustic Soda, NaOH. This may be used, but since it is no more effective for the purpose intended than is Soda Ash and in view of the injury to the human skin and its destructive effect on other materials, it is not made use of for Navy Boiler Compound. It is an effective alkali and is used in various special boiler compounds. Caustic Soda is largely used in conjunction with tan bark extracts for use on very hard feed waters ashore. It is a stronger alkali than soda ash and moreover, in waters containing magnesium salts, it is more acceptable, since it precipitates a more insoluble magnesium hydroxide. Such compounds, however, always contain a large percentage of water and are very disagreeable to handle.

Milk of Lime, $Ca(OH)_2$. This can be used as an alkali, but is not recommended because it is not entirely soluble in water and soda ash is much more effective in its action of neutralizing acids and in breaking up the scale forming salts. Milk of lime, if fed in sufficient quantities, also tends to form a lime scale which can be built up to an objectionable degree. Milk of lime may be useful in putting on a thin protective scale on the surface where such a course is desirable. Lime has been used for Marine boilers for many years, but the soda compounds appear to be more effective and are also easier to handle and keep in storage. Lime has a useful place in the lime-soda pre-treatment of boiler water for shore plants. Calcium carbonate exists in boiler feed water usually as the soluble salt $CaCO_3.H_2CO_3$; when lime is added to this water, it combines with the H_2CO_3 and precipitates all of the calcium carbonate.

Sal Soda, $Na_2CO_3.H_2O$. Sal soda differs from soda ash in that it contains about 60 per cent of water, whereas soda ash contains scarcely any water. The action of sal soda is very similar to soda ash, but soda ash is a more concentrated form and is somewhat cheaper. Sal soda is quite widely used for feed water treatment and is an ingredient found in many special boiler compounds. There are no particular objections to its use, and its use is sanctioned for boilers of Naval auxiliaries (Shell boilers).

Kerosene. This material has a pronounced effect in softening and removing various kinds of scale and especially mineral oil deposits. It is used in cleaning and boiling out boilers where deposits have accumulated. It should not be introduced into a steaming boiler. It is not recommended for use by various authorities, owing to the danger of explosion and the bad effect an excessive amount may have on gaskets and jointing materials. Its use is authorized by the Engineering Manual in conjunction with boiler compounds for boiling out badly scaled boilers, and if used with proper precautions and limitations, it becomes an effective help in the boiling-out process.

Cutch. This is a material derived from mangrove bark. It is quite generally used in connection with feed water treatment, because of its action in keeping scale-forming ingredients in solution. It contains tannic acid 40-45 per cent. It apparently has a colloidal and cleansing effect. Cutch is used in many boiler compounds and is also used in conjunction with soda ash or sal soda.

Flaxseed. The feeding of extract of steamed flaxseed into Marine boilers has been found beneficial in preventing scale and corrosion. This has also been used on locomotive boilers. It is found to be considerably more expensive than using soda ash or Navy Boiler Compound. The extract from the flaxseed appears to have a colloidal effect on the scale-forming salts and also a protective effect to the metal. Its effect appears to be somewhat allied to that of Cutch.

Colloidal Boiler Compounds. So-called colloidal boiler compounds are being offered for use. These attempt to hold the scale-forming solids in solution and to discharge these in the form of sludge by blowing. Most of these compounds also claim to be effective scale removers. It is claimed that they penetrate the scale and break it off so that it can be removed by blowing.

Actual use appears to indicate that they have such effect to a certain degree, but in most cases the ordinary ingredients used in Navy Standard Boiler Compound, if used intelligently, will have a similar effect. When, for any reason, considerable scale is formed in boiler tubes, an endeavor to remove this should be made by boiling out, using Boiler Compound, with possible addition of certain other material such as kerosene, dextrine, starch. This scale can ordinarily be softened and its removal accomplished by blowing down. Such scale deposits can also be removed in ordinary operation by adding extra boiler compound or special materials.

As a general rule boiler scale is not removed by the solvent action of any boiler compound. When boiler compound is properly added to a boiler feed water, it precipitates the scale-forming ingredients and the softened water in the boiler no longer forms a scale on the boiler tubes; for this reason, the scale already on the tubes, having a different co-efficient of expansion from the metal of the tubes, cracks off and collects in the mud drum or bottom of the tubes. In other words, a badly scaled boiler will rid itself of scale, provided the water to the boiler is properly treated.

UNDESIRABLE MATERIALS.

There are various materials sometimes proposed for boiler water treatment or used as ingredients in special boiler compounds, which have harmful effects and are to be guarded against.

Mercury. This is sometimes put into boiler compounds or scale removers. It may be effective as a scale remover, but it also is very likely to corrode the boilers unless it is all very carefully removed. Its use is dangerous.

Weak Acids. Weak acids are sometimes proposed for use. Dilute Hydrochloric Acid is the most common one. This will remove scale and is used also for cleaning scale out of condenser and evaporator tubes. It is effec-

tive as a scale remover and if the complete removal of the acid after its cleaning action is completed could be guaranteed, its use under certain conditions might be sanctioned. However, the complete removal of the acid and the difficulty of checking its action just at the proper time, make its use in boilers a fairly dangerous procedure.

Graphite. This is a scale remover, but it also corrodes the metal. Its use is prohibited by the Navy and by the A. S. M. E. code.

Barium Salts. These are used to a certain extent on shore. Their use is objectionable because they are poisonous. They are not authorized by the Navy. Barium aluminate is an efficient reagent, but quite costly.

Caustic Potash. Caustic potash is too expensive for use as a boiler compound. Its action would be in no wise different from that of caustic soda. Its use is not sanctioned on account of bad effect upon the human skin and its corrosive action on certain materials.

Sodium Aluminate. Sodium aluminate is a salt formed by dissolving aluminum hydroxide in sodium hydroxide. When used as a boiler compound, it acts like an alkali in neutralizing acidity, also as a gelatinous material, since aluminum hydroxide is precipitated when the alkaline properties of the salt are neutralized. The precipitated aluminum hydroxide is mainly of value, in that it tends to adhere to oily particles or precipitated matter and keep them in suspension in the boiler water, whereby they are readily eliminated by blow-downs. This is used in certain special boiler compounds for colloidal effect. It is not authorized for use by the Navy. The action of these aluminates is considered more or less uncertain.

PARTICULAR VARIATIONS IN CONDITIONS.

Navy Standard Boiler Compound is designed to give a feed water treatment that will cover the general conditions met with Naval boilers. This means use of distilled water, with slight occasional addition of sea water due to leaks, etc., and the possibility of considerable mineral oil in some cases. When these conditions are varied considerably, special treatment may be desirable.

Excess of Salt. In case the amount of salt is increased, this is taken care of by using an increased amount of Boiler Compound. However, in special cases, where corrosion may become more active under such conditions, certain corrosion inhibitors may be added. These are: Sodium Bichromate and Sodium Silicate. An addition of 5-15 per cent of these substances to the Standard Boiler Compound appears to be advisable in such instances.

One large shipping company has found it desirable to use the following compound anti-corrosive bricquettes on occasions when a very considerable amount of salt leakage is encountered:

66 per cent Soda Ash.
10 per cent Sodium Bichromate.
16 per cent Sodium Silicate.
8 per cent Moisture.

The following extract of a letter is quoted:

"We issue instructions to substitute these bricquettes for the U. S. Navy Standard Compound should the chlorine reading come to about 1000 grains per gallon caused by some unforeseen trouble which might develop, for instance in the condenser. The sodium bichromate in an alkaline solution will prevent corrosion in a general way which might be best explained by the chemical reactions given below, furnished to the writer by Mr. J. H. Gullak:

"'$Na_2Cr\ O_4$ plus $3Fe(OH)_2$ plus $4H_2O$ equals $3Fe(OH)_3$ plus $Cr(OH)_3$ plus 2NaOH.

"'I believe the best way to explain the action of bichromates or rather chromates, as bichromates cannot exist in alkaline solution, is to state the fact that bichromates (chromates) in alkaline solution are reduced to basic chromium salts by soluble ferrous salts. In other words, chromic acid ($Cr\ O_3$), oxidizes, ferrous oxide (Fe O) to ferric oxide (Fe_2O_3).

"'Obviously when ferrous hydrate is formed on the surface of steel or iron a corrosion or rusting is beginning. Now, if chromates are present in a solution which is in contact with steel or iron which is starting to corrode (rust) the chromate will be reduced at the point of corrosion and a thin film of *chromic hydrate* will immediately cover the point of corrosion thereby preventing any *further* corrosion. As long as this film is immersed in a liquid or kept moist, the film will continue to function as a protective covering. In other words, if the film should dry and crack, the corroding liquor would again attack the metal until another film was formed'."

"The sodium silicate forms the binder in making the bricquettes and is also a further safeguard for corrosion due to its tendency of forming a protecting film on the iron. The action of sodium bichromate on the iron will only take place where corrosion is active but the action of sodium silicate in forming a film will continue as long as it is present in the boiler water. We therefore instruct our Chief Engineers that this is only to be used in an emergency and to immediately go back to our regular treatment as soon as satisfactory repairs have been accomplished. The percentage of sodium silicate in the anti-corrosive bricquettes is not enough, in our opinion, to cause any developments of scale that will interfere with the heat transfer and the film caused by its deposit on the heating surface will wear off in a short period of time."

Excess of Oil in Boilers. In this case, the percentage of tri-sodium phosphate, tannin, and dextrine, may be increased to 50 per cent over the regular proportion, to overcome the undesirable action of oil in its tendency to cause foaming or to make an oily deposit on the heating surface.

When an unusual amount of mineral oil is introduced into a boiler, adding more dextrine, starch, or extract obtained by steaming flaxseed, will help.

There are other passivifiers which are used to some extent on shore. Castor oil and alum may be mentioned. They should be used with great caution. In some instances they may be useful and have been used in some shore boilers. Their use is not authorized by the Navy.

Hard Shore Water for Make-up Feed. In case it is necessary to use hard shore water for make-up feed in Marine boilers, a new situation is introduced, but this condition can be allowed for. If hard waters are to be used for make-up feed, it is perhaps preferable to use tri-sodium phosphate by itself in sufficient quantity to make the water slightly alkaline. It would be but little more expensive than Navy Standard Boiler Compound. It costs, in barrel lots, approximately six cents per pound, while Navy Standard Boiler Compound costs approximately five cents per pound.

GENERAL PRACTICE OF REPRESENTATIVE SHIPPING COMPANIES.

A number of these companies have adopted the use of Navy Standard Boiler Compound and are following the directions for its use. Other companies employ boiler compounds supplied by certain manufacturers and are guided by the advice of the manufacturer. Others use sal soda or soda ash and endeavor to keep the water slightly alkaline. In some cases a certain percentage of Cutch, or other material which is a source of tannin, is added. Where special cases of corrosion are found, special treatments are

applied, usually on advice of some feed treatment expert. The directions formulated by Messrs. Speller, Harter, Bashore & Smith, published in Marine Engineering 25-1920, and which are described in Sterling's Marine Engineers' Hand Book, appear to cover the general situation as practiced in the Merchant service. Some vessels with Scotch boilers use no boiler compound and do not suffer serious troubles. They are probably slightly scaled and feed water not allowed to become acid.

EXPERT ADVICE.

In cases where Naval boilers develop any special defective condition, as to scale, corrosion, burning of tubes, or a tendency to foam or prime, the matter should be taken up with the Experiment Station through the Bureau of Engineering for advice and information. In such cases, samples of water taken from boiler should be sent to the Station for analysis. In case of scale trouble, an analysis or sample of scale should be sent. A very complete statement of defective conditions and methods of operation should be given. After an investigation of such situations, the Station may be able to advise the temporary use of special mixtures to overcome the particular adverse conditions. Navy Standard Boiler Compound is designed to meet average conditions only and such matters as excessive oil, excessive air, the presence of free acids, extra salt leakage, special scale deposit, or action due to peculiarities in the metal or of the feed water, may require some special treatment to overcome the defective conditions. This is particularly so where active corrosion is going on in spite of the alkalinity of the water or where foaming and priming are experienced to an objectionable degree, even when the rules for handling such cases as laid down in Bureau Manual are carried out.

REMOVAL OF AIR FROM FEED WATER.

The complete protection of Marine Boilers from internal corrosion is confined to two fields: (1) Treatment of feed water to render it as non-corrosive as possible, which is fairly well accomplished by carrying out present instructions of the Engineering Manual; and (2) preventing air from gaining entrance to boiler. While the fitting of proper deaerating apparatus will eliminate the air and dissolved gases to a point where corrosion is negligible (about 7 parts per million 0.7 cc per liter), any reduction in the air content in the boiler water and steam is very desirable. There are many fairly simple precautions that may be taken to keep air out. The following may be mentioned:

(*a*) Prevent feed pumps from sucking air.

(*b*) Keep feed tank as hot as possible and see that it is properly vented. The vent can be run through a small distiller to avoid loss of vapor. A suction fan can be installed to draw off the mixture of air and vapor.

(*c*) Closed feed heaters should be properly vented on the water side so that any air separated by the heat can be gotten rid of before going to the boilers.

(*d*) Deactivators, consisting of bundles of iron lath or iron turnings, placed in feed tanks or in feed system, will tend to take out the oxygen.

DEGREE OF ALKALINITY TO PREVENT CORROSION.

Present information indicates that for any particular condition of water with reference to content of air, dissolved gases, salts, and temperature, there is a point where the corrosive action is somewhat less than at other points.

This point is quite difficult to determine by calculation, owing to the very many variables. It can be found practically for any particular sample of water as described in Speller, page 344, in Engineering Manual, or in Navy Boilers (Lyon & Hines), page 291. This is done by taking a sample of water and increasing the alkalinity until the point of least apparent corrosion, on some sample pieces of steel boiler tubing, is found. This being done, it will serve as a guide or point to aim at in carrying the alkalinity for that particular condition. However, experience indicates that for average conditions in Marine Boilers, there is but slight difference in the corrosiveness of boiler water as between .1 per cent and .5 per cent of normal alkalinity, 50-250 parts per million of sodium carbonate alkalinity, 3 to 15 grains per gallon.

There is some laboratory data available, which indicates that higher alkalinity than this may, under certain conditions, give somewhat better results for preventing corrosion, but higher alkalinity also causes other troubles, such as priming and the destruction of composition fittings, valves, packings, etc., which are very undesirable. There is also apparently some danger in causing or accelerating what is known as caustic embrittlement. In view of this, it is most likely that the best overall results will be obtained if the alkalinity is maintained between the above points. If priming is experienced, the lower alkalinity may be favored. If rather complete deaeration of the feed water is obtained and salt leakage carefully prevented, the alkalinity also can be lowered and of course less boiler compound will be required to maintain the alkalinity aimed at.

In Marine Boilers there is not much danger of encountering caustic embrittlement unless an alkalinity much in excess of the above is carried for long periods of time. But if a corrosion test of water should indicate that an alkalinity in excess of .5 per cent should be carried and this can be done without any priming troubles or destruction of fittings, it may be desirable to carry such higher alkalinity. Experience indicates that in general the above limits are sufficiently high to take care of any temporary excess of acid, from whatever cause, and to have a sufficiently high alkalinity to secure reasonable freedom from corrosion of the kind that can be stopped by maintenance of alkalinity. Corrosion cannot be prevented altogether unless there is complete deaeration and also a definite margin of alkalinity. The ideal conditions practically are an approximate complete deaeration, freedom from salt, and a low alkalinity sufficient to neutralize any acidity from whatever cause and of such strength as will inhibit corrosion due to the very limited air, other dissolved gases, or impurities that may be in the feed water. There are many ifs and ands. The problem of treating feed water is not at all an exact science, but approximate steps in the right direction continuously and consistently applied will give quite satisfactory results.

Various degrees of alkalinity have been recommended by various authorities. The Navy Engineering Manual has set the limits at between .2 and .5 per cent of normal alkaline solution. This corresponds to 100-250 parts per million or 6-15 grains per gallon. Speller, in his book on Corrosion, recommends 150 parts per million. The pamphlet recommended for use by Merchant Marine, where soda ash is recommended as the water treatment, recommends 15 grains per gallon. These different authorities are in some general agreement and the Navy rule sets certain limits which can be met in practice without much difficulty. The drawback to high alkalinity is the tendency to prime, which is quite objectionable. The carrying over of solid matter into the turbines is a fruitful cause of blade deterioration and the carrying of these particles into the superheaters also will tend to cause deterioration. Clean, dry steam is desired for economy and to avoid turbine

and superheater trouble. This being so, it is desirable to carry as low an alkalinity as is safe to ensure non-corrosive boiler water. The best alkalinity to carry will depend upon the purity of the boiler water and other operating conditions. By experience and trial, including corrosion test of tube samples, the lowest desirable alkalinity for any installation can be found. Under satisfactory conditions as to air and salt leakage, it probably will be found at about .3 per cent of normal alkaline solution, 9 grains per gallon, 150 parts per million. If we aim at too low an alkalinity, we will not be prepared for any sudden and undiscovered salt leak; if too high, we may have some priming and dirty steam. In high pressure and high rates of steaming, the trouble from priming is much greater than with low rates and low pressure. While fairly high alkalinity may be carried in one case, in the other it cannot well be done unless the feed water is quite free from air, salt, or other foreign matter. It will therefore be seen that no hard and fast rule can be applied that will be the best for a variety of conditions. Where certain limits are given, the particular boiler plant should endeavor to find the approximate point within these limits which is best suited to it. If this is done the best practical results will be secured.

SCALE.

The scale problem is somewhat separate from, although associated with, the corrosion problem. A certain amount of eggshell scale is protective on heating surfaces not subjected to high pressures and high rates of evaporation. On the other hand, any appreciable scale deposit, particularly an uneven deposit, acts to prevent heat transmission and may cause local burning out, as well as local corrosion. Anything but the lightest possible protective scale is therefore undesirable. Navy Boiler Compound, by the action of the soda and tri-sodium phosphate, breaks up the scale forming salts, and by the collodial action of the tannin, dextrine, and starch, tends to hold these and other finely divided foreign matter in suspension, or as a sludge, and thus prevents the deposit of these substances on the heating surfaces. The amount of earthy matter (sand, etc.) and oil in the feed water also has an effect upon the scale or deposit that may be formed. It is particularly desirable to keep the oil in suspension in the form of sludge, or as soft particles in the lower parts of boilers away from the action of the flame. It is very difficult to allow the proper amounts of particular ingredients to take care, fully, of the varying conditions of these sources of scale and deposit. The tannates, dextrine, starch, etc., act as cleansers; tending to keep the solid matter in suspension, or in such shape that it can be blown out by means of bottom blow. Navy Standard Boiler Compound has enough of these materials to take care of average conditions. There may, however, be cases and special conditions where an extra amount of some of these ingredients may be desirable as scale removers and preventatives. Starch is perhaps the most available material and it may be added in limited amounts to help the cleansing ability of the compound, without running the risk of obtaining too much alkalinity.

However, scale is usually the result of some temporary condition or of neglect and unless the deposit is more or less unusual, it can be removed by the process of boiling out with Navy Standard Boiler Compound plus kerosene as described in Engineering Manual. For oil deposits, the addition of starch will also add to the cleansing effect. Also certain special cleaners and detergents will remove mineral oil deposits. A mixture of soda ash plus 10 per cent starch, and preliminary kerosene soaking, is likely to be as effective as most of the patented detergents or cleaners. When scale is heavy and especially hard it may require mechanical cleaning. If proper

precautions are taken and Boiler Compound used intelligently, the necessity for mechanical cleaning of tubes should be very slight. This applies to operating conditions where a certain amount of salt leakage may be present. The use of Boiler Compound and other precautionary measures contained in the Engineering Manual should prevent any undue accumulation of scale and should also enable scale deposits, when once formed, to be removed without mechanical cleaning. Experience indicates that where proper care is taken and Boiler Compound conscientiously and continually used in accordance with directions, scale does not collect to any considerable extent. Scale is *not* a necessary evil but the result of *neglect* or *defective operating conditions*, which may be both avoidable and unavoidable. The principal reason for scale deposits is failure to carry out instructions for preventing its formation.

PROTECTIVE FILMS

The artificial production of protective films or light protective scale is a rather important item in connection with preventing internal boiler corrosion and hence something to be considered in connection with feed water treatment. Such films and light coat scales can be put on without much trouble and expense and under certain conditions it is extremely desirable to do this, particularly when active corrosion is found to be present and is not due to obvious neglect to keep boiler water alkaline.

Milk of lime may be used for this purpose and its use on new boilers is recommended by high authorities. Its use is also recommended in the case of partial retubing of boilers that are more or less scaled. The idea here is to put a slight protective scale over the new metal surface which may be subjected to corrosion due to action being concentrated on certain parts which are bare, while the major part of the surface has some protective film or scale.

Silicate of soda and bichromate of soda have the property of forming protective films and can be fed into the boilers for this purpose, along with the boiler compound, or separately, when so desired. It would appear desirable to do this where boilers are laid up wet. Their use should be restricted to special conditions where active corrosion is discovered and is not stopped by the ordinary use of Standard Boiler Compound. The effect of the use of these materials can only be definitely told by proper examination and inspection. If no good effect is noticed after a reasonable application, then use should be discontinued. These ingredients, as mentioned elsewhere, have an undesirable tendency to cause priming, particularly when considerable salt is present. The use of these materials must be intelligently directed and some fairly definite knowledge of their action is a prerequisite to their successful use. They may very easily be used in excessive amounts; but their judicious use will often stop active corrosion.

PRETREATMENT OF WATER.

Pretreatment or softening of water, as applied to shore plants, cannot be well applied to Marine and Naval boilers and, as the make up feed used is already soft, there is not very much occasion to use pretreatment. However, it is advisable to add boiler compound to the water in the feed tank before it enters the boiler and to have attachments by means of which a definite amount of the compound can be fed in at a uniform rate, so as to put the water just before entering the boiler into the desired condition. All make up feed should be put into feed tank or condensers and not direct into boiler. If a proper feed of boiler compound is given to the feed tank and proper operating conditions are maintained, there will not be as much need

for injections into individual boilers. The feed tank also, by having heating coils, can act to a certain extent as an air remover, thus further putting the water into more suitable condition before entering the boilers.

TREATMENT OF BADLY PITTED AND CORRODED SPOTS.

If some parts suffer from extensive pitting, grooving, channeling, and the worm eaten type of local corrosion, these surfaces should be cleaned out and filled with metallic cement, so as to inhibit further action. If the depressions are of any considerable extent, so as to weaken the part appreciably, it would be well to fill up the depressions by welding. The welding, if properly done, will, to some extent, give back some of the lost strength, and this is very important in cases where the defect has been due to over stress. This practice of welding, in case of badly corroded parts, will restore the strength to a very great degree and in many instances avoid replacement of parts. It is permitted by the A. S. M. E. boiler code and it is believed that its more extended application, properly supervised, would very greatly extend the useful life of the corroded parts and make the operation of the boilers safer than by merely cleaning out the depression and filling it with cement. Welding up the spots with suitable welding rod will also tend to prevent the recurrence of the pitting or corroding action. Welding can be applied much more extensively than it has been in boiler repairs and in giving additions of built up metal where they may be desirable. Weak parts in boilers, even if not weakened by corrosion, can be strengthened by the intelligent application of welding.

USE OF NAVY BOILER COMPOUND FOR SHORE BOILERS.

Navy Boiler Compound can readily be applied to shore plants, especially where there is no permanent hardness in the feed supply or where distilled water is used for make up. The conditions at tide water power houses are often quite similar to that on board ship. In some cases the water supply may be such that a variation in the mixture should be made to secure the best results. This can often be done by adding some additional ingredient in certain proportions. In certain localities pretreatment of feed water is quite essential, but often the use of Navy Standard Boiler Compound in the boiler after the pretreatment, is desirable. Pretreatment does not always allow fully for the changes that take place in the boiler.

The treatment directed for ships' boilers may or may not be suitable for any particular shore boiler and should not be blindly followed.

SUMMING UP.

Practical operators, on reading the usual chemical literature on corrosion and the use of corrosion deterrents, are very likely to be confused by the apparent complicated and confusing statements made in regard to the use and action of various materials under greatly variable conditions.

The conditions affecting Marine and Naval boilers are fairly uniform where distilled make up feed is used and where every effort is made to keep down salt leakage and there is a reasonable effort to keep out air. This being the case, practice in regard to feed water treatment for Marine work can be fairly well standardized for these particular conditions. This has been done by the instructions for using Navy Standard Boiler Compound and practice of many American shipping companies of using either Navy Boiler Compound or materials that are generally an approximation thereto. This is sound practice and furthermore a certain line of ships in certain service might find a certain variation from such standard practice, desirable. The

amount of shore make up feed, oil in boilers, pressure and steaming rate, usual salt leakage, natural tendency to prime, due to design and arrangement of boilers and machinery, will somewhat vary conditions.

Hence, where the conditions are different, a somewhat different treatment of boiler water is entirely justified. Such variation, however, should be based on scientific basis, knowledge of the chemical actions involved and of the action of the feed water under the operating conditions imposed. Some of the possible variations are outlined in this pamphlet, but it would be better to obtain the recommendation of an expert on feed water treatment before deciding upon any considerable variation in the application of feed water treatment.

For the Navy, such expert information is supplied by the Engineering Experiment Station. The problem of boiler water treatment for Marine work is sufficiently well understood by experts in this line so that a fairly satisfactory treatment can be prescribed for any installation and any ordinary condition of operation. The proper treatment, however, cannot be definitely applied without having a chemical analysis of the water and a definite knowledge of the construction of the boilers, as well as the general operating conditions. One matter that is likely to be very upsetting is an un-uniform condition of make up feed. If surface water is used, its impurities may vary considerably after rains or storms; at tide water the state of tide may affect it. Sometimes the discharge from industrial and chemical plants will cause variation. When such variable conditions exist, frequent analysis of the water and change in treatment is in order.

From a review of Naval practice and the practice of representative commercial shipping companies, it appears that the following is the best general practice for Marine boilers:

(*a*) Take all practical steps to keep air out of boilers, feed tanks, and feed systems.

(*b*) Take all practical steps to prevent salt leakage.

(*c*) Use distilled water for make up or use only shore water known to be harmless.

(*d*) Prevent oil from getting into boilers.

(*e*) Keep make up feed as clean as possible.

(*f*) Use any practical devices in feed tanks, piping, etc., which will remove oxygen. This includes heating and venting, the use of deaerators, and the use of deactivators having iron laths, turnings, etc., which take up oxygen. See that feed enters boilers by means of a properly distributing pipe or trough. It is desirable to have this arranged so that air and dissolved gases can be released before feed mingles with the regular water.

(*g*) Use boiler compound to maintain constantly a low alkalinity of feed water, both in feed tank and in boiler. This can best be done by maintaining a constant drip of alkaline compound solution into feed tank and supplement this by special doses to individual boilers as required. After a certain amount of experimentation the correct rate at which compound is to be added can be determined and if all conditions are satisfactory, the amount of compound required will be comparatively small. When a routine has been established, under which boilers are kept clean and active, corrosion arrested, the desired end has been attained.

(*h*) Make daily tests of feed water in boilers and feed tanks and endeavor to keep alkalinity between 2/10 and 5/10 per cent of normal solution; or from 100 to 250 parts of alkalinity to the million; or 5-15 grains per gallon.

(*i*) Use bottom blows as needed to rid boiler of the collection of sludge, dirt, or scale deposit. If boiler is clean, the blowing can be greatly lessened. Blowing should not be done any more than necessary.

(*j*) Clean boilers internally at regular intervals and if scale deposits form, boil out boiler, using soda ash or Navy Standard Boiler Compound with the addition of about 5 per cent by weight of starch. The addition of a slight amount of kerosene will also add to the cleaning ability. The kerosene may be added to the boiler just before it is pumped out, so that it will be distributed to all of the surfaces; or, it may be put in the boiler just before it is pumped up preparatory to boiling out.

(*k*) If the carrying out of the above regime does not prove satisfactory, look for some special condition. If scale forms, locate source and endeavor to remove it. If active corrosion shows, add anti-corrosive material such as sodium silicate or bicarbonate of soda. If chronic priming is encountered, reduce alkalinity or add extra tri-sodium phosphate and tannin to boiler compound. If this fails, call for some expert advice.

If trouble is not removed, have boilers and water examined by feed water expert to determine special condition and apply the remedy to such condition. The trouble may be due to some special impurity in the feed or due to some special condition of operation or design. An excessive amount of air may be the source of trouble.

Aside from water, there are mechanical causes for deterioration of boiler material. Where material is subjected to repeated stress and the design is somewhat weak, or where material has been overstressed in fabrication, there is the phenomenon or corrosion fatigue. This accounts for cracks and grooves, usually found at knuckles, corners of sharp flanges, etc., below the water line. This class of trouble is not specially due to bad feed water, but may be accelerated by high alkalinity, intermittent service, and the rapid heating and cooling of boilers. Where such defects occur, they may be cleaned out and welded up and pressure should be reduced if necessary. The real remedy, however, is to renew the defective part, if this is practicable. This type of corrosion is due to fatigue and in many cases the condition of boiler water has no particular effect upon it. To the uninitiated, this type of corrosion may be confused with that which is caused by corrosive elements in the water.

The rules for use of boiler water treatment, as laid down in the Manual of the Bureau of Engineering and that contained in the instructions prepared by Messrs. Speller, Bashore, Harter & Smith, which appeared in Marine Engineering, 25-1920, appear to cover the situation quite satisfactorily as far as average conditions are concerned.

Special cases may require some variations, as has been indicated herein, but there appear to be no late developments in the use of feed water treatment for Marine boilers that are likely to change materially the practical situation as described in Section 4 of Sterling's Marine Engineers' Handbook. The particular new developments are the discovery of special substances that have either a cleansing effect or an anti-scale-forming effect and the proper application of some materials which will better tend to avoid priming and foaming. Air free steam is probably the next big thing to go after, as far as preventing the deterioration of boilers, piping, and turbines.

APPARENT PRESENT TENDENCIES IN AIRPLANE DESIGN*

By V. E. Clark,

Vice-President and Chief Engineer, Consolidated Aircraft Corporation.

A discussion of the tendency in airplane design might deal with one or both of two phases: (*a*) the past and present, and (*b*) the future. In this

* Paper presented at the National Meeting of the A.S.M.E. Aeronautic Division, Buffalo, N. Y., April 25-26, 1927.

paper the author, lacking the courage to venture predictions, will confine himself to a brief review of the immediate past.

It seems that a fair answer to the question, "In what direction is airplane design leading?" would be: "Scattering in all directions." At no time during the brief history of aviation have there been *successful* airplanes of so many widely different types—aerodynamic and structural.

One reason for this encouragingly healthy state of affairs may be that more and more engineers are being developed who combine native imagination with a sound knowledge of the pertinent fundamental sciences and a sufficient amount of practical experience (and horse sense) to justify risking the hazards of pioneering, instead of cautiously copying a traditional scheme that has "worked" but which may have become conventional merely because it happened to have been the luckiest result of several early cut-and-try endeavors. One says "encouragingly healthy" with the firm conviction that it would be most unfortunate for us to attempt to standardize at this time, on the assumption that the possibilities of the science have been sufficiently thoroughly investigated and developed to warrant standardization. To be trite, the longer one observes aviation the more one must realize what a tremendous amount is to be learned.

The diversity of development between nations is much greater than that between constructors of any one nation. While there is no defined "school" of design adopted within any one nation, there is consistently more similarity intranational than international. One reason for this is the influence of governmental policies as affected by peculiar contemplated military problems and by the availability, among national resources, of special basic materials. Great Britain, for example, must build airplanes which will be durable in all sorts of climates, hot and cold, dry and wet, and which may be maintained in service thousands of miles across the water from their home factories. Other nations lack certain indigenous basic materials. The United States, in this particular, is very fortunate. We have iron, chromium, molybdenum, nickel, silicon, manganese, vanadium, aluminum, copper, magnesium, cadmium, spruce, birch, long-fiber cotton, nitrates, and fuel and lubricating oils. In fact, nature has endowed our country with every element necessary for the fabrication and operation of aircraft. For the few elements we lack, we have acceptable substitutes.

GREAT BRITAIN.

Of the great powers, England is probably the most conservative in aerodynamic design and in the use of materials and manufacturing processes. By far the great majority of modern successful British airplanes are of the type which has flown well for the longest time; the tractor biplane with wings of thin section externally braced, usually with a two-bay cellule and usually of equal spread and chord. Most of the construction is of wood, with fittings of sheet steel. Captain De Haviland, whose DH-4 we know so well in this country, has designed a great number of useful machines, in the general scheme of all adhering to the type of aerodynamic design and of construction which he adopted many years ago. His fuselages are of wooden sticks taking compression and forming the framework for an outside covering of plywood which completes the structure by tying the sticks together and taking diagonal tension loads.

In England, welding in vital structures is discouraged. Very little duralumin (we shall use this term for aluminum-copper alloys for convenience at the cost of accuracy) is used, notwithstanding the fact that one of the foremost airplane manufacturers, the Vickers Company, fabricate this material commercially in various forms. The Boulton & Paul Company builds its structures of very thin high-grade steel sheet, with sections so formed and riveted together as to resist local buckling failures.

The development of La Cierva's "Autogiro," invented in Spain, is evidently being encouraged to some extent. In this machine vertical lift is obtained, not by flexed wings, but by four monoplanes above the fuselage rotating propeller-wise about a vertical axis. Rotation is started by external power before take-off and continues due to the nature of precision of air forces, during revolution, on this peculiar airscrew, as long as there is relative air velocity. The machine is propelled through the air by a conventional tractor propeller-motor unit mounted in a standard fuselage with tail surfaces. Due to relatively high "tip" velocities of wing blades, the airplane can take off and land at comparatively slow true air speed, with resulting short run. The gyroscopic effort of the mass of the rotating wings, with large diameter, tends to stabilize the machine in the air. It is very doubtful, however, whether this machine will compare favorably with an airplane with fixed wings, when it comes to carrying a given load a given distance with given power *in a given time.*

Handley Page has been developing, for a number of years, "slots" for wings. The auxiliary entering edge vanes and trailing edges of wings to form these slots may be opened and closed during flight. The purpose is to delay discontinuity of air flow above an airfoil, or "burbling," with resultant loss of lift, until a very high angle of attack has been reached. The result is that a given airplane, with given wing area, can land at a given speed with about sixty per cent more gross weight (perhaps over a hundred per cent more pay load) than it could without the slots.

FRANCE.

France has built a tremendous number of military airplanes. Tourists in Europe may hold that the experienced constructors of France have built so many military machines that they can never learn to build *comfortable* passenger transports.

French airplane ideas are well diversified. Many of their modern machines are "sesquiplanes"—with a wing and a half—the upper plane having a much greater spread, and usually greater chord, than the lower. The famous Breguet XIX, which has flown 3,400 miles cross-country without landing exemplifies this type. There are also many monoplanes braced externally by a single pair of tension-compression struts extending diagnonally out from the bottom of the fuselage. This very attractive type was developed by Loening in the United States and by the Morane-Saulnier Company in France. The Wibault is a very interesting French machine of this type—an all-metal monoplane of rather simple construction covered by thin sheet "Alferium." In his latest machines Wibault uses no wires, all loads being taken by compression-tension members.

French engineers seem to have no fear of the "rack and ruin" from landings. This is evidenced in three ways: (1) The very small travel shock absorbers; (2) The tendency to attach important structural members for wing bracing to the undercarriage; and (3) The general lightness, even flimsiness, of the structure throughout the airplane—ill-suited, one would think, to withstand the racking incident to hundreds of landings—average landings as we know them in this country. It may be that all French pilots are artists at landing, or that they are expected to land only on fine fields, or it may be that French engineers have learned how to make structures very flexible and shock absorbing and yet strong and durable. Or perhaps the military are willing to sacrifice an airplane every so often in order to save weight and the last word in performance. At any rate the French school in this respect is far different from ours.

The Société d'Emboutissage et de Constructions Mécaniques has installed a large equipment of special machinery toward reduction to real production

methods. Their construction is largely of stamped sheet metal in shapes and combinations which look expensive but may not be.

GERMANY.

There is no more interesting development than that in Germany. Restrictions imposed by the Allies after the armistice made it illegal for Germany to build airplanes which even remotely resembled military machines. Certain other restrictions at that time put a premium upon getting the most out of a limited amount of horsepower. These rules have forced German engineers into lines of endeavor which may result, within the near future, in Germany's leading the world in commercial aviation. Their airplanes are, from the time of first conception, designed with the sole thought of commercial utility. Except in a few instances, the general design schemes of other so-called commercial airplanes are modifications of those of previous military machines. Furthermore, German engineers and scientists have been forced into a deal of fundamental research, at which there are none more thorough and systematic, in aerodynamics and in the development and use of suitable materials.

The most successful engineers today, Dornier, Rohrbach, Junkers, and others, apparently agree on at least two important principles, viz., (a) the monoplane, and (b) the stressed skin or covering of thin duralumin sheet.

Junkers has always used his skin, on wings, fuselage, and other surfaces in the corrugated form, which has a distinct advantage in resisting "drum head" vibration and resulting fatigue failure at rivet-attachment points. Corrugated sheet has of course the added advantage of being capable of taking compression loads in, and bending loads normal to, the direction of the corrugations. It has, however, no rigidity in the other direction, is hard to work in such manner as to give a neat appearance where it is necessary to change to a "flat" along edges, and there is some question as to the efficiency of rivets as they must be pitched in a curved surface. Junkers has preferred the straight cantilever wing, strongly tapered both in plan and depth, usually located at the bottom of the fuselage with considerable dihedral. In this cantilever he has not used prime beams but, rather, has replaced chord members by a number of round seamless duralumin tubes, distributed throughout the entire wing section and triangulated together by riveted duralumin strips, beaded to give rigidity in compression except at the ends which are flat and riveted to the tubes. These strips lie in every direction necessary to complete, in conjunction with the skin, the trusses for lift, drag, and torsion.

The structure is very rigid but, to all appearances, very costly in man-hours, because of the tremendous number of rivets which must be headed from the inside of tubes and at other inaccessible or, at best uncomfortable places.

Notwithstanding the fact that a closed tube is the most economical (from the strength-weight standpoint), reliable, and determinate section with which to take compression loads, and avoids *edges*, which, in duralumin, gives us lots of worry, it is a bad thing to which to rivet, as the rivet heads inside cannot be inspected.

FLYING BOATS.

Dornier, who builds flying boats and land-type airplanes, convertible as seaplanes, locates his wing above the fuselage, usually with some gap between. His wing is not tapered either in plan or depth. It is braced externally by long struts attached to the bottom of the fuselage, one leading to each of the two main wing beams. These reduce by half the length of the cantilever. For normal flying loads, these struts are in tension.

Being long columns, they are weaker in compression to take reverse loads, but the reverse loads are of far less magnitude than the normal loads. His two wing beams and other important highly stressed parts are of formed heat-treated alloy steel. He uses flat thin-sheet duralumin skin to take stresses from drag and other loads. The skin is stiffened by channels or flanged U-sections, laid at right angles to each other. The channels lying in direction of flight are riveted outside the skin, top and bottom, and take the place of the compression cap strips in our old-fashioned ribs. Thwartship channels are riveted inside the skin. His airplanes are covered all over by duralumin sheets, except the ailerons, where he uses fabric to reduce weight and static hinge moment, thereby reducing the danger of wing flutter.

On his flying boats lateral stability on the water is obtained (?) by streamline sponsons built out from the main hull. On the Super-Wal two engines are mounted in tandem above the center of the wing.

Both the Super-Wal and Rohrbach's latest flying boat have succeeded in getting off the water with a useful load greater than the weight of the empty machine with power plant.

Rohrbach, who specializes in rather large flying boats, has evidently given a great deal of attention to the reduction of production costs. This has lead him toward an adaptation of shipbuilding practice.

His monoplane wing is cantilever except that, by means of two tightly strung wires leading down and inboard from a station about half-way out, he imposes an initial bending moment and stresses on the inboard part of his wing girders of the opposite nature to those imposed in normal flight, thereby reducing the latter. In spite of the fact that the wing is well above the hull, he has chosen to use a very strong dihedral. At first glance one would say that the resulting lateral stability would be so great that maneuverability would be poor. He has stated, however, surprisingly enough, that this dihedral is necessary *to reduce instability*, thereby, of course, improving maneuverability. Until very recently his wing has been without taper in plan, but now, we hear, he uses some taper. His wing loading is extraordinarily high.

His study toward reducing production costs has been along the lines of dividing the wings and other major parts into a great number of separate units. He finishes fabrication of each of these, which permits a great number of men to work without getting in each other's way, and makes the final assembly very simple. Comparatively unskilled labor may be used.

For example, instead of building two wing beams, attaching a lot of ribs, and then applying a covering on this skeleton, he does something like this: The wing is divided into three parts by planes perpendicular to the chord and extending athwartship. The prime structural part is a sort of box girder and includes what we ordinarily call our two wing spars, together with drag bracing, and everything that is located between the two spars. The rounded entering-edge and the trailing-edge sections are built up separately and bolted in place in final assembly. These are readily removable for purposes of inspection and repair. All parts of the wing are of flat sheet metal, with angle sections for mutual attachment. The prime structural box girder is like a long thin caisson or tank, made up, following his principle, of a number of sections, covered top and bottom with comparatively thick imperforate duralumin sheet which serves to resist drag loads. At front and rear are his "wing spars," each made up of a web member and chord members. The web member is of heavy sheet with lightening holes which provide access to the inside of the "tank" for riveting and inspection. The chord members of the individual spars are

double angles to which the skin, top or bottom, is attached. Between the four walls of the "tank," extending fore and aft, are a number of fore-and-aft "baffle-plate bulkheads" each of which takes the place of the web of the central portion of an old-fashioned rib. These also are of flat sheet with lightening holes. All these parts are built in sectional units and then the entire box girder riveted together by angle and channel pieces.

HOLLAND.

The Fokker Company has adhered to the practices which it originated and which it has found successful through many years. The wings are cantilevers, tapered in plan form and depth from root to tip. The cantilever principle is used in biplanes as well as monoplanes. The wings are entirely of wood, the two main spars being a box section with laminated-spruce chord members and double plywood side webs, with vertical spruce members placed vertically within the box at proper intervals, and all glued, screwed, and tacked together. The ribs and covering are also of plywood, the covering taking all drag loads and eliminating the necessity for internal drag trussing. The structure of fuselages is entirely of welded seamless steel tube, the forward portion usually in the form of a modified Warren truss and the rear portion a Pratt truss, with diagonal wires as tension members. Fokker machines have always been noted for their ease of control and stability.

UNITED STATES.

Briefly, in our country we build military biplanes, usually externally braced, sesquiplanes in our single-seater pursuits, and many monoplanes for commercial uses. Our fuselage structures are tubular, usually welded seamless steel, but sometimes duralumin. Our wing spars are usually of spruce, and our covering of doped cotton.

The particular phase of aviation in which we, without argument, stand at the head of the world is our Air Mail Service, which operates at night over bad country and in all sorts of thick weather. Our Air Mail Service has been, in this work, remarkably successful, largely due to the pilots and to the efficiency of ground maintenance service. However, one cannot help believing that, even with the installation of light beacons, emergency landing fields, etc., our air-mail pilots, in their efforts to keep up their fine record for reliability, are still operating under conditions which are prohibitively hazardous. A lot must be done yet toward protecting them. It has been suggested that, for night flying in thick weather across bad country, a string of "Neon" tube lights, spaced at intervals of about 300 yards along the entire course, might go far toward solving the problem, but one wonders, when contemplating the cost of light beacons, landing fields, wrecked airplanes, radio installations, meteorological services, etc., whether there may not be some other way more reliable, less costly, and *less hazardous to human life* than our present transcontinental Air Mail Service, which is getting more and more complicated as we learn more about it.

The airplane has the peculiar great inherent advantage of being able to travel swiftly at any time in a straight line from any one place to any other. But when we have a set route such as the New York-Chicago-San Francisco line, perhaps some such means as a streamline container, with no wings, riding on an overhead cable, with or without motorman, propelled by electric motor or by airplane propeller-motor unit, might be better, all things considered.

POWER PLANT.

There has been, since the war, great development of, and an encouraging degree of confidence in, air-cooled engines. The most popular of these are of the fixed radial arrangement, usually nine-cylinder, one piston having a master connecting rod, with the other eight rods connected thereto, all to one crankpin. The Bristol "Jupiter," developed in England and built in large numbers, under license, in France, and the Pratt & Whitney Wasp in the United States, have proved that 450 horsepower is practical in a unit. For this horsepower the radial air-cooled engine appears to be the lightest type, when means of cooling are included. How much more power it is good to take through one crankpin must be proved.

The inverted "V" and "in-line" arrangements, which have certain advantages, have proved practical.

The Napier Lion in England and the Hispano-Suiza "Broad-Arrow" in France are fine examples of "close-coupled" water-cooled engines. Each has twelve cylinders, arranged in three banks of four. Italy, with her "Schneider Trophy" Fiat, has shown that it is possible to get 900 horsepower for 900 pounds, exclusive of cooling system.

All these engines are essentially for military use, however. Cost of construction, operation, and maintenance, which must be paramount for commercial uses, have been neglected.

DIVISION OF POWER PLANT.

There are those who argue that in using more than one engine we are only admitting weakness in power-plant reliability or in lack of landing fields. This is true, and it may be that the day is almost here when confidence in our power plant (engine proper and ignition, lubrication, fuel supply, and cooling systems) and in having a landing field always fairly handy, will have grown to the point where we shall willingly put all our eggs in one basket. The compromises in the multi-engine arrangements are many. Parasite air resistance increases badly, engine controls and fuel-supply systems become complicated, and often we must have several rudders in order that at least one may always be in the slip stream of the propeller that's turning. There is, of course (except in the case where it is necessary to provide proper fields of vision for a bomber), no excuse for division of power plant unless the airplane can fly with one engine out, and it is very confusing and discouraging to try to calculate a proper business-like airplane that can really fly, with full load, with one engine out. What we are after, in commercial aviation, is to carry the greatest number of pounds a given distance with the minimum of horsepower. When we reduce the load carried by an amount such that the airplane can really fly with half, or a third, of the power gone (more than that, really, because of reduced propeller efficiency with engines full out at reduced air speed), we are not carrying enough load per horsepower installed to be operating economically.

SUMMARY.

As proof that the science is yet fluid, the author cites the following:

England has no welded structures; we use little else in our fuselages.

Fokker developed the welded steel-tube fuselage structure in Germany and still uses it. We in the United States followed him, but Germany did not, nor has any other nation.

France has wooden fuselages and wings of metal structure; we have metal fuselage structures and wooden wing structures.

England uses little duralumin, Germany little else, France some, we less.

England is for biplanes, Germany for monoplanes.

England's biplanes have thin wings with, usually, two-bay cellules. Our biplanes are usually single-bay, with moderately thick wing sections.

Several types of monoplanes are in use: (*a*) The pure cantilever, tapered in plan and in depth (Fokker); (*b*) The cantilever with Rohrbach's wires under initial tension; (*c*) The semi-cantilever, with constant chord and depth, braced underneath by diagonal tension—compression struts (Dornier); (*d*) The semi-cantilever, with diagonal struts, with taper in depth and diagonal or chord from root to tip. There has been a leaning toward type (3) in France, Germany, and, lately, in the United States.—"Aviation," May 9, 1927.

METAL AIRCRAFT.

By Roy G. Miller,

Engineer, Naval Aircraft Factory, Philadelphia, Pa.

The United States Navy has long appreciated the many advantages of metal aircraft construction as compared to wood and has done much to foster its steady development. Private manufacturers have been encouraged by contracts for experimental construction and the Bureau of Standards and Naval Aircraft Factory have undertaken a great deal of pure research and experimentation on Navy funds.

While the Army and many of the private manufacturers have favored use of steel in metal construction, the Navy was quick to realize the advantages of the light aluminum alloys and has concentrated the greatest effort on their improvement and application. By far the greater portion of the structural weight of an airplane lies in the compression members. Assuming geometrically similar sections an Euler column may be provided in duralumin weighing only 60 per cent as much as a steel column designed to support the same load. This quality in duralumin is due principally to its low specific gravity providing bulk in compression members. In the case of tension members where bulk is not desirable, the best alloy steels are preferable to duralumin.

The greatest single difficulty which has been encountered in the use of aluminum alloys has been susceptibility to corrosion. Properly heat-treated duralumin, insofar as corrosion is concerned is somewhat worse off than the grades of aluminum ordinarily used for cooking utensils. It has been found that the proper heat-treatment for realizing the best physical properties of duralumin is fortunately the same for developing the greatest resistance to corrosion. Quenching in cold water from 500 to 510 degrees centigrade is the approved treatment. Annealed duralumin is practically susceptible to "intercrystalline corrosion," the bogy which has excited much comment lately. Proper heat treatment refines the granular structure of the metal and keeps most of the $CuAl_2$ in solution where it belongs rather than permitting it to distribute itself very liberally around the margins of large grains. Protection and maintenance problems with duralumin are very similar to those encountered with steel. Various paints, varnishes and grease have proved to be helpful. There has been no non-corrosive metal coating developed, however, which is electro-positive to duralumin and which will offer the same protection which zinc offers to steel. The "anodic" treatment, in which an oxide coating is applied to duralumin by electrolysis, has shown very remarkable results, particularly when used in conjunction with various of the organic protective coatings.

Duralumin lends itself to various manufacturing processes because of its relatively high ductility immediately after heat-treatment. Shaping after

heat-treatment eliminates the possible warping due to heating and quenching besides insuring high physical properties. Cold working brings about a substantial improvement in the physical properties.

Early metal construction of aircraft in this country leaned toward the "all metal" types of the German Junker and Dornier machines. The thinnest aluminum alloy sheets which it has been found practical to use for covering the wings of airplanes is several times as heavy as fabric. The only justification for its use lies in the possibility of it contributing to a portion of the structural strength. The Junker machines have consistently held to the corrugated wing covering contributing to the rib strength. The early Dornier machines employed a smooth metal covering designed to carry a portion of both rib and spar stresses. Sand load tests at the Naval Aircraft Factory indicate that a suitable stiffened metal covering will carry a maximum unit stress of from 20,000 to 23,000 pounds per square inch. One of the chief advantages claimed for the metal covered wing is its resistance to torsional deflection. That this quality, taken alone, is not all-important is demonstrated by the reports from abroad indicating structural failure, due to wing flutter, of two Dornier pursuit planes. It seems important to combine with torsional stiffness an air foil of good stability characteristics and a structure with its gravity axis well forward. A good modification of the metal covered wing was embodied in several Dornier models in which the forward portion of the wing was metal covered and the rear portion fabric covered. It is rather interesting to note that the latest Dornier wing (on the "Superwal") is fabric covered. Another German constructor, Rohrbach, has developed a very interesting wing, covered with smooth metal. The first all metal airplane which the United States Navy undertook was the NM-1, somewhat lighter and more efficient than the Dornier construction but very similar.

The present trend on Navy projects is toward fabric covered metal structures. It has been found that metal structures may be built which weigh about half as much as conventional wood construction. A few of the structural features which have contributed most to weight saving are the following:

(*a*) Cambering of structural members subjected to combined axial and distributed loads to reduce or eliminate secondary stresses.
(*b*) Eccentric fittings for the reduction of stresses in principal members.
(*c*) Eccentric structural sections to distribute material according to loads.
(*d*) Dependence upon friction to increase the strength of self-aligning compression members.

The development of metal construction at the Naval Aircraft Factory has aimed at a combination of light structural weight, serviceability and low cost of production. Parts are designed with the idea of mass production, in case of emergency, constantly in mind. It was this consideration which has led the factory to do considerable work in pressed metal construction. It has been found extremely difficult to compete with tubular members on a basis of strength-weight in the case of extremely light and fragile members, such as ribs, but hope is entertained of closely approaching the built-up tubular wing beam with pressed construction. One of the chief advantages claimed for pressed construction is its freedom from reliance upon a multiplicity of fastenings for its primary strength.—"The Tech Engineering News," April, 1927.

AERONAUTICAL POWER PLANTS.

A Comparison of Air and Water Cooled Engines as Well as Discussion of the Diesel Engine.

By C. Fayette Taylor.

Associate Professor of Aeronautics, Massachusetts Institute of Technology.

The present situation with regard to power plants for aircraft is most interesting. While the fundamental type of engine used, that is the four-cycle gasoline engine, has not changed since the first flight made by the Wright brothers, continuous improvement and refinement in detail has made the airplane engine of today quite a different piece of apparatus than it was even so short a time as ten years ago. The goal which designers have considered the ultimate ideal, namely, the development of a horsepower for every pound weight of engine, has been well-nigh achieved in the F. I. A. T. engine which won the Schneider Cup Race this year. This engine, complete with water in the jackets, but without radiator and piping, weighed 1.03 pounds for each horsepower developed. This is equivalent to approximately 1.6 pounds per horsepower with a complete cooling system of the normal type. The development of the air-cooled radial engine is quite comparable with this, the Pratt & Whitney "Wasp" and Bristol "Jupiter" engines weighing about 1.5 and 1.6 pounds per horsepower respectively complete with cooling system. Since the figures given for these two engines are based on their service ratings without any special forcing for racing purposes (as in the case of a F. I. A. T.), it is evident that from the weight standpoint the air-cooled radial is at the present time slightly ahead of the corresponding water-cooled installation.

The competition between the water-cooled and air-cooled engines for supremacy in the air constitutes one of the most interesting phases of the present situation. While the air-cooled power plant usually has a lower weight per horsepower than the corresponding water-cooled power plant, there are still many engineers who feel that the water-colled power plant possesses other advantages sufficient to offset this difference in weight. Accompanying this article are two illustrations showing the same type of airplane fitted with a water-cooled and air-cooled engine of approximately equal power. Figure 1 shows a Curtiss single-place "pursuit" airplane equipped with the Curtiss D-12 engine, a high speed, twelve-cylinder, V type, water-cooled power plant rated at 430 horsepower at 2250 R. P. M. The radiator is placed in a so-called "tunnel" just below the engine, and evidently occupies a relatively small portion of the total frontal area presented by the airplane. Figure 2 shows essentially the same airplane with the Pratt & Whitney "Wasp" air-cooled radial engine rated at 425 horsepower at 1900 R. P. M. At first glance it would appear that this type of engine offers considerably more air resistance than the water-cooled type owing to its exposed cylinders. It would also appear to restrict the field of vision of the pilot as compared with the water-cooled engine. While these objections are true to a certain degree, the difference is not so great as to be considered very serious by most pilots. The lighter weight of the air-cooled power plant gives the airplane a higher rate of climb and a higher ceiling than is obtained by the water-cooled power plant of approximately equal power, and the fact that the engine is shorter and more compact concentrates the weight of the entire airplane more nearly at its center of gravity, which, together with the lower engine weight, makes this airplane considerably more maneuverable than with the water-cooled power plant. In this connection it is interesting to note that a good measure of maneuverability in a fighting airplane is the

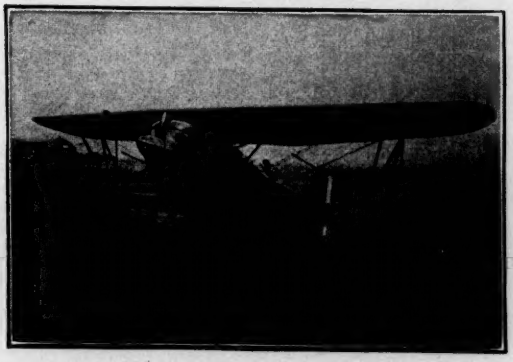


FIGURE 1.—CURTISS P-1B "HAWK," ARMY TYPE, CURTISS D-12 ENGINE.

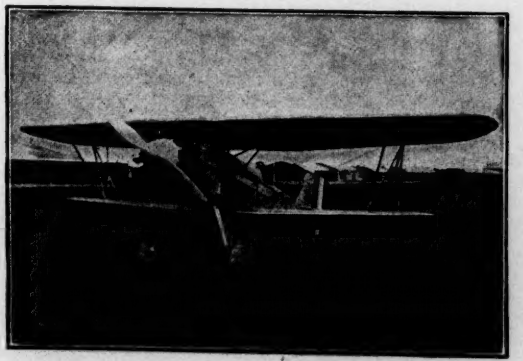


FIGURE 2.—CURTISS F 6 C-4 "HAWK" NAVY LANDPLANE, PRATT & WHITNEY "WASP" ENGINE.

PICTURES THROUGH THE COURTESY OF CURTISS AIRPLANE AND MOTOR CO.

shortest radius of turn which the airplane can make at full speed. That airplane which can turn in the shorter radius has a distinct advantage in bringing its machine guns to bear on an airplane which must use a longer radius of turn. The maximum speed of the airplane illustrated is very nearly the same for both power plants, with perhaps a slight advantage in favor of the water-cooled installation. Many competent authorities feel, however, that such a slight advantage in maximum speed is much more than offset by the advantages in climbing and maneuvering ability of the air-cooled installation. These advantages, considered together with the greater simplicity and ease of overhaul of the air-cooled radial, seem to justify the prevailing opinion that the air-cooled engine is distinctly superior to the water-cooled engine for most purposes under present conditions.

It will be interesting to observe the progress of this competition between the air-cooled and the water-cooled engines, and to note whether the air-cooled power plant continues to gain in popularity as rapidly as it has in the past two or three years.

The fact that the air-cooled power plant has the upper hand at the present time is emphasized by the tendency in Europe toward this type of engine. Many of the old established manufacturers, such as Lorraine Dietrich and Salmson, who have confined themselves almost exclusively to water-cooled engines in the past, have recently brought out air-cooled models. In England there is a distinct tendency toward the air-cooled radial engine although several water-cooled engines are also holding their own very well.

In the writer's opinion there is one consideration in favor of the water-cooled engine which may enable it to continue to compete successfully with the air-cooled engine in certain types of airplanes. This is the fact that the capacity for heat dissipation of an air-cooled cylinder is limited by the surface area of the cylinder itself and the fins which can be placed thereon. In the water-cooled engine, however, the cylinder area exposed to the cooling water is not yet the limiting factor, and increased cooling may be obtained by enlarging the radiator surface and increasing the rate of circulation of the water. This means that in the development toward higher piston and crankshaft speeds which is now going on, the air-cooled engine may reach a limit beyond which the required rate of heat dissipation exceeds the capacity of the cooling surface. It seems quite apparent that if this limit exists at all in the case of the water-cooled engine, it will occur at a very much higher power per unit of engine displacement than in the case of the air-cooled engine. This is borne out by the results which have been recently obtained by racing automobiles operating at crankshaft speeds of over 6000 R. P. M., and developing a horsepower on considerably less than one cubic inch of piston displacement. This figure has not been nearly approached in any air-cooled engine of which the writer is aware. Another method of increasing the power per unit of piston displacement is by the use of the supercharger. This is a form of air pump which delivers air to the engine at a pressure higher than atmospheric, thereby increasing the weight of intake charge and the power output. If this method of increasing power output is carried very far, it may be that the limitation of cooling surface in the case of the air-cooled engine will give the water-cooled engine an advantage.

While this keen competition is going on between the various types operating on the normal gasoline engine or Otto cycle, the intensive development of the fuel injection or Diesel cycle is being carried out both in this country and abroad with a view toward making it adaptable to the high piston and crankshaft speeds which are necessary for a light weight engine. The advantages of the fuel injection cycle for aircraft work are chiefly its ability to use a low grade fuel which involves much less fire risk than gasoline and is at the same time cheaper. It is also felt that the elimination of

the electric ignition system will be of great advantage. The fuel injection cycle lends itself very well to the two-stroke type of operation in which there is a power stroke in each cylinder for every revolution of the crankshaft. Obviously if this two-stroke cycle were developed to a point equal to the four-stroke cycle, it would be possible to obtain twice the power from a given engine at the same speed, or to decrease the speed by one-half and still develop the same power. In this country the National Advisory Committee for Aeronautics has been conducting some very valuable fundamental research on fuel injection in their laboratories at Langley Field, Virginia. They have developed an apparatus for ultra high speed photography of the injection spray. Investigation by means of this apparatus has resulted in some very fundamental and valuable knowledge regarding the action of high pressure spray nozzles for introducing fuel into the very high pressure atmosphere existing in the cylinder of a Diesel engine just prior to the end of the compression stroke. This investigation has now reached a point where it can be safely said that the fundamentals of fuel injection, at least as regards the introduction of the fuel, have been definitely established, and it remains for manufacturers to take up the application of these fundamentals to the development of truly high speed fuel injection engines. In Germany, which was the birthplace of the Diesel engine, a great deal of valuable research and development is going on, and one company, the Maybach, has actually put on the market a high speed, automotive, Diesel engine. This engine is rated at 150 horsepower at 1500 R. P. M. with a fuel consumption from .39 to .44 pound per brake horsepower per hour. The weight is 2650 pounds or nearly 18 pounds per horsepower. While this may seem excessive when compared to airplane engines, it represents a distinct advance over earlier practice in the fuel injection field. In England the Beardmore Company is developing a large high-speed Diesel engine which is reported to be very promising. This particular development, however, is surrounded with the greatest secrecy. Reports are that it will develop 650 horsepower with a weight of 3200 pounds and a fuel consumption of under .4 pound per horsepower hour. This is a weight of something less than 5 pounds per horsepower which is exceptionally good for this type of engine. In this country the Navy is developing the Attendu oil engine for air-craft work, but so far this engine is in the experimental stage only. Several American companies are developing injection engines for automotive work.

The difficulties to be overcome before the fuel injection engine will compete with the gasoline engine for air-craft service, are very great. Nevertheless astonishing progress has been made, and it will be interesting to watch further developments. Since the fuel injection engine may not lend itself well to air-cooling, it is quite possible that the air-cooled engine will be displaced by the water-cooled engine in the not far distant future.

The interesting thing about this whole situation is the fact that it is in a state of flux and that no one type or style of engine is so firmly fixed that it is certain to hold its own indefinitely. At the present time, however, the high speed fuel injection engine is the only fundamentally new type which appears to have possibilities of being a dangerous competitor to the present types. The gas turbine and steam plant which have been spoken of in connection with aeronautical work, present problems which at the present time appear to be insurmountable, so that there is little danger of either of these being a serious competitor in the aeronautical field, at least in the near future.—"The Tech Engineering News," April, 1927.

EROSION OF SURFACE CONDENSER TUBES.*

Investigations Show That Turbulent Motion of Water in the Water Box May be One of the Chief Causes of Erosion.

By Sir Charles A. Parsons.

The problem of the failure of the tubes of surface condensers is so well known that it seems only necessary here to allude to a few of the salient facts bearing upon the question. While no adequate explanation has as yet been assigned for such failure, many attempts have been made to overcome it. On the theory that it is caused by electrolytic corrosion, counter-electromotive force has been applied to neutralize the action; on the theory that it arises from chemical action, such means as coating the inside of the tubes with a bituminous paint or with a protective scale of oxide have been tried. None of these measures has proved to be more than palliative in its effects, and sometimes not even that. In a few cases more expensive metals are being adopted for the tubes, such as cupro-nickel or monel metal. For many years bell-shaped mouths have been fitted to the inlet ends of condenser tubes to produce a smooth stream-line flow into the tubes,† and this is claimed to prevent the formation of a *vena contracta* by the sharp square entrance to the tube and the liberation of oxygen and other occluded gases from the water which cause corrosive action at the tube entrance.§

In most cases of failure it has been observed that certain of the tubes are eroded, corroded, pitted, and eventually holed, but always or nearly always from the water side, that is to say, from the inside surface. The action is usually confined to tubes in certain regions of the condenser tube plate, and if such tubes are replaced from the common batch they have usually failed just as quickly, while in other positions in the tube plate the original tubes have remained immune, so that there appear to be distinctive areas in which the conditions favor corrosion or erosion. Further, it appears that the action is greatest at the entry ends of the tubes, frequently extending only a few feet from the mouth. These facts seem to suggest that the cause may be hydro-dynamical rather than electrical or chemical, and in the light of the experiments described in this paper they seem to indicate that these areas of erosion or corrosion are associated with regions of turbulent motion of the water in the water box.

The object of the present paper is to give an account of some experimental investigations which have been designed to throw light upon the actual conditions attending such regional disturbances in the water box, and the manner in which they affect the character of the flow through the tubes in their vicinity, also to investigate the possibility that the pitting of condenser tubes may in reality be due to water hammer of collapsing vortices, which is known to be a potent cause of erosion of screw propellers and of the impellers of centrifugal pumps and water turbines.

A paper was read before the Institution in 1919 by the present author and Mr. Stanley S. Cook on the "Cause of Erosion of Propellers." The paper recounted the investigations carried out by the Propeller Erosion or Corrosion Committee of the Board of Invention and Research. In that paper experiments with a water hammer cone were described, in which it was

*Paper read at the spring meetings of the sixty-eighth session of the Institution of Naval Architects, London, April 6, 1927.

†Vide P. C. Parker's remarks in the discussion on Dr. Bengough's paper, "Transactions of the North-East Coast Institution of Engineers and Shipbuilders," Vol. XI., Part 2, 1923.

§ Vide Serial Report of the Prime Movers Committee, 1926-27, of the National Electric Light Association of New York, U. S. A.

shown that by concentrated collapse of a vacuous cavity in water under atmospheric pressure small holes could be punched through brass disks, demonstrating the production by this means of shock pressures as high as 150 tons per square inch. The conclusions of the Committee were that the powerful and erratic erosion experienced with propellers was due to vacuous cavities in the water arising from eddies caused by struts or bossing, or by excessive slip of the propeller itself, which cavities collapsing on the surface of the propeller blade caused repeated blows and erosion of the metal.

The first of the present experiments was designed so that the behavior of the water in the water box and also in the tubes could be observed and, if desired, photographed.

An apparatus was constructed consisting of a small wooden water box, the front being of plate glass, with a brass tube plate for ten tubes. To facilitate observation the first 3 feet of the four tubes of the central vertical row were made of glass also, the tubes of the side rows were omitted, and instead retarding plugs were fitted giving the same discharge as a 15-foot length of condenser tube. The discharge from these side holes was led into a separate chamber immediately behind the tube plate. The four central glass tubes passed through the back of this chamber, and were joined at their ends by clamped rubber tube couplings to brass tubes 12 feet long, making a total tube length of 15 feet. They were also surrounded by a rectangular water tank with plate glass sides so that (the refractive index of glass and water being nearly the same) the water inside the tube could be seen without appreciable refraction. The discharge from the long tubes was taken into a measuring tank with a glass front, so that the trajectory of the water issuing from the tubes could be observed.

Closely fitting between the front plate glass of the water box and the tube plate, an inner and movable water box of circular shape was fitted into which the water was led tangentially through a socket fitting. This inner water box was moved by a lever passed through a stuffing box, guides and stops controlled its motion, so that it could be moved up and down across the face of the tube plate. An air vessel on the water supply to the box maintained a steady pressure of about 10 pounds per square inch. With water entering the water box at a speed of 8 feet per second, which was also the speed of the water through the tubes, a vortex filament was observable near the center of the circular inner box, extending across from the glass plate to the tube plate. By moving the box this vortex could be brought over the mouths of tubes Nos. 2 and 3 of the four central tubes, the tubes No. 1 and No. 4, top and bottom, being only presented to the outer zones of the vortex filament.

The following results were observed when a vortex filament was in this way brought over the mouth of a tube, through which up to that moment the water had been flowing with a speed of 8 feet per second.

1. The vortex was drawn into the mouth of the tube.

2. The flow in that tube was partially arrested, the discharge being reduced in a fraction of a second to about one-fifth of its previous quantity.

3. The vacuum at the core of the vortex brought over the tube mouth was momentarily intensified by the arrest of momentum of the water already in the tube.

4. A vacuous thread extended momentarily into the tube for about half the length of the glass portion, and then collapsed irregularly at various points.

5. Silvery looking fringes appeared momentarily on the entry edges of all the four tubes whether under or near the vortex.

6. It was observed that at the instant when the vortex was brought over the tubes 2 and 3 it developed a momentary bifurcation into the neighboring tubes 1 and 4; the bifurcation being of such short duration as to be difficult to see.

The apparatus was next modified for continuous working in order to ascertain if pitting of the tubes could actually be produced in this manner. The glass tubes were replaced by tubes of brass, continuous for the first 12 feet of their length, and then extended to 15 feet by attached 3-foot lengths of similar brass tube. A solenoid, with a make-and-break relay, was fitted to operate the lever to oscillate the inner water box, at a rate of about 15 cycles per minute and a motor-driven centrifugal pump and drain tank maintained a continuous circulation, the system being filled with brackish water from the river Tyne.

The solenoid operated lever was so adjusted by guides and stops as to bring the vortex filament alternately over the mouths of the second and third of the four central tubes, so that a comparison of these tubes afterwards with the first and fourth, which were not subjected to the action of the central part of the vortex filament, would enable any difference in effect to be definitely attributed to this action. The apparatus was run for 1450 hours, or about two months' continuous work, after which the four tubes were taken out and the first 3 feet of each sawn in two for examination. Pitting was observed at the entry of all the four tubes, extending from about ⅛-inch to a few inches along the several tubes, beyond this the tubes were apparently unaffected. In one of the tubes several pits penetrated about half way through the thickness of the tube. There appeared to be very little difference in the amount of pitting in the two tubes subjected to the vortex filament, and those subjected only to the rapid transverse flow of water across their mouths.

The experiments will, however, be continued with varied conditions, including transfer of heat across the tubes to the water as in ordinary condenser practice, and it is hoped that these may throw further light upon the subject, and produce experimentally the erosion of the tubes in the central portions of their length.

In order to investigate the character of the regional disturbances occurring in a water box of usual type a further experiment was made. A model water box was constructed, about a quarter full size of an actual condenser box, with a tube plate for one hundred tubes of 5/8-inch diameter. These were bent and spread out in groups so that the discharge from each tube could be observed. The water box was fitted with a glass front. Town water was used, which was circulated by a centrifugal pump. The velocity in the tubes was about the same as in an ordinary condenser, i. e., about 8 feet per second. The tubes being of different lengths retarders were fitted near their mouths to give a discharge equivalent to tubes of 15 feet length, and to maintain the standard velocity in all the tubes. Regions of strong turbulence were distinctly observed in the water box, and the vortex centers were seen to move about from tube to tube over certain areas. The discharge from some of the tubes was found to show sudden variation; this variation corresponded, as regards the tube positions, with the vortex motion in the box, although the sudden drop of velocity was only about one-half that observed in the previous experiments with the circular water box. It, however, must be borne in mind that the vortices, in relation to the size of tubes, would only be of about one-quarter the size they would be in an average full sized condenser, and also smaller than the single vortex in the circular water box experiments.

In conclusion, it is suggested that the experiments, as far as they have been carried out, seem to lead towards the view that one of the chief causes of the erosion of condenser tubes may lie in the turbulent motion of the water in the water box of the condenser, and that this cause could be mitigated by enlarging the area of the inlet passages so as to reduce the velocity of the water as much as possible before entering the box, or entirely removed by arranging in the water box a grid of suitable mesh and with

passages of depth somewhat greater than their width. By the passage of the water through this grid such turbulence is practically destroyed. Grids of this kind have been tried in conjunction with the experimental apparatus and it is found that with such a grid, when the whirl chamber is moved across the tube plate exactly as before, the velocity at the discharge end of the tubes remains perfectly steady, and no vortex motion is visible in the box either behind or in front of the grid.—"Marine Engineering," June, 1927.

ARC WELDING.

By J. F. Lincoln,* Cleveland, Ohio.

Arc welding is a comparatively old process—that is, the first patents in connection with it were taken out more than thirty years ago. However, its use commercially, on a large scale, is comparatively recent.

Undoubtedly the repair of the interned German ships in the harbors of the United States, during the late war, brought arc welding to the attention of the American people a good deal more forcefully than any other application which has ever been made. The repair of these ships as we see it now was a comparatively simple operation, and while it undoubtedly saved a considerable amount of money and time for the American Government and increased materially the efficiency of the American intervention in the war, nevertheless the actual use of welding in this case and in all other repair cases must be of secondary importance.

While the use of arc welding for repairs undoubtedly saves this country in excess of one hundred million dollars per year, by far its greatest value in the future is going to be in the replacement of riveted steel and castings with arc-welded steel. The fundamental reason why this replacement will come is twofold.

ADVANTAGES OF ARC-WELDED STEEL PARTS OVER RIVETED OR CAST-IRON PARTS.

Compared to riveting, arc-welded steel will give the full strength of the joint, while rivets will give but from 50 to 80 per cent of the sheet strength when the riveted joint is made in the usual commercial manner. This means, therefore, that any structure which is made of riveted steel and depends on the strength of the joint for its efficiency must have from 30 to 100 per cent more steel in it than would be necessary were an arc-welded joint used. What this would amount to in the aggregate is a stupendous sum, as can be well appreciated.

However, there is still another application which is of very much greater importance, namely, the employment of arc-welded steel in place of castings of all kinds. The fundamental principles involved in this substitution are as follows:

Cast iron has a tensile strength of approximately 10,000 pounds per square inch; that of welded steel is approximately 50,000 pounds.

Cast iron has a modulus of elasticity of 12,000,000; that of steel is 30,000,000.

Castings on an average cost 6 cents per pound; rolled steel, 2 cents.

The factor of safety necessary for the same degree of safety will be half as great with steel as with cast iron. Therefore, if a pressure vessel in

* Vice-President, Lincoln Electric Company.

Contributed by the Machine Shop Practice Division for presentation at the Spring Meeting, White Sulphur Springs, W. Va., May 23 to 26, 1927, of "The American Society of Mechanical Engineers," 29 West 39th Street, New York. All papers are subject to revision.

which the strength of the shell is the limiting factor is made from cast iron, it will cost for the same degree of safety approximately twenty-five times as much as if made from rolled steel; if a base or any structure which is used for resisting bending is to be made, the cost will be but approximately 15 per cent as much if made from structural steel as if made from castings.

When the total amount of this saving is considered, it is easy to see that the sums involved run into figures that are enormous even to the American people who are accustomed to speaking glibly of billions.

Regarding the problems which are involved in taking advantage of these fundamental principles, it is quite evident that if the plan were merely a matter of replacing one metal with another there would be no doubt about its immediate adoption. But it is not nearly so simple as that; one great virtue of the casting is the fact that it can be made into any shape with very great ease, while rolled steel must of necessity (from its very method of manufacture) be made in certain definite shapes and those only.

These shapes can of course be so made that they will be the most efficient for the kind of work they are designed to do, and if they can be adopted directly without change they will do any work better because of this shape than would be possible with most cast shapes, entirely aside from their greater strength and stiffness.

POSSIBILITIES OF REDESIGN OF CAST INTO ARC-WELDED PARTS OF ENORMOUS IMPORTANCE.

However, there are a great many cases where it is necessary to make a structure which is radically different from any shape directly procurable from the steel mills, and therefore the possibilities of the designing engineer in redesigning cast structures into those using welded steel are of enormous importance. In fact, the designer of the future who can apply this new tool to best advantage will be an outstanding engineer.

The importance of this seems so great to the company with which the author is connected, that it has offered three prizes of $10,000, $5000, and $2500, respectively, for the best applications of arc welding to the redesign of present-day structures, hoping in this way to get the brains of the country at work considering the proposition more closely, more intelligently, and more thoroughly, so that the savings which such redesigned will afford may be brought about in the shortest possible time.

One very definite matter which is holding back the universal acceptance of arc welding as an economical producing tool is the fact that habit so largely controls our minds. Mankind in general accepts without question the theory that if a precedent has been established, it must of necessity be right and should continue to be followed. Of course, all laws are based on this fundamental principle and perhaps that is one reason why there is so much dissatisfaction with law, but it would appear that the engineer should be the first to reject tradition when it is self-evident that tradition is wrong in the light of present-day development.

The author believes he is safe in saying that there is no best manufacturing method and no best manufacturing tool which is today the same as it was fifteen years ago; that there are very few which are the best today that are the same now as they were five years ago; and further that any manufacturing concern manufacturing any product today exactly the same as it did six months ago, is not pursuing the best possible way, and that if any product has not been entirely redesigned during the last five years, probably the concern manufacturing it is rapidly losing ground.

SAVINGS IN COST DUE TO REPLACING CASTINGS WITH ARC-WELDED STEEL PARTS.

In spite of the tendency to go slowly with changes as radical as that of replacing castings and rivets with welding, there has nevertheless been enormous progress already in its application. At the present time most of the bases of motor-generator sets and motor-driven pumps, and work of a similar simple nature formerly made of cast iron have been redesigned in structural steel. Some buildings have been erected this way, and some bridges have also been made of arc-welded steel. In these cases the saving has ranged from 85 to 15 per cent of the previous cast-iron or riveted-steel cost.

Other examples of this same fundamental scheme of applying arc-welded steel in place of castings are as follows:

In the case of the rotor spider for an electric motor:

Cast Iron		Arc-Welded Steel	
Cost of iron casting	$6.75	Cost of rolled steel	$1.28
Labor cost	2.94	Labor cost	4.37
Total	$9.69	Total	$5.65
Weight, 70¼ pounds.		Weight, 43¼ pounds.	

Another case is that of the end ring for a motor which heretofore has always been made of cast iron. The comparative costs follow:

Cast Iron		Arc-Welded Steel	
Cost of rough casting	$2.89	Cost of rolled steel	$1.126
Labor cost	0.195	Labor cost	0.407
Total	$3.085	Total	$1.533

Another case is a motor-base rail which heretofore has always been made of cast iron, the comparative costs being as follows:

Cast Iron		Arc-Welded Steel	
Cost of rough casting	$4.992	Cost of rolled steel	$1.536
Labor cost	0.117	Labor cost	0.617
Total	$5.109	Total	$2.153
Weight, 77 pounds.		Weight, 66 pounds.	

Another interesting application is that to the motor extension for an elevator base heretofore always made of cast iron. The comparative costs are:

	Weight	Cost
Cast iron	184 pounds	$11.04
Arc-welded steel	109 pounds	5.45

A cast-iron wheel for a shop truck has been replaced by one made of arc-welded steel. In this case a section of T-stock is bent into a circle and welded, a piece of pipe being used for the hub, and the flat stock for the spokes. The comparative cost follows:

Arc-Welded Steel		Cast Iron	
Cost of rolled steel	$0.35	Cost of rough casting	$1.75
Labor cost	0.33	Labor cost	0.10
Total	$0.68	Total	$1.85
Weight, 12.5 pounds.		Weight, 25 pounds.	

The comparative costs of a number of other parts which have a more or less wide application (since they are indicative of what can be done in the redesign of any part from cast iron to steel) are given below.

Cast Iron		Steel	
12-inch Pulley			
Material	$7.90	Material	$1.20
Labor	2.99	Labor	1.85
Total	$10.89	Total	$3.05
Weight, 79 pounds.		Weight, 40 pounds.	

	Weight	Cost
Wall Box		
Cast iron	35 pounds	$2.10
Steel (material $0.42; $0.36)	14 pounds	0.72
Support		
Cast iron	27 pounds	$2.27
Steel (material, $0.42; labor, $0.23)	14 pounds	0.65

It will be noted that in no case is the overhead included in these costs. The reason this is not done is not because of the fact that it will change the final result, but because overhead is a widely varying quantity and in amount is to a considerable extent controlled by the amount of inventory, as inventory, depreciation, storage, and interest charges are invariably a part of the overhead.

It is self-evident that in general the labor cost is higher in the case of arc-welded steel replacing cast iron than it is for the original casting. Therefore, if overhead were included with its usual percentage, the ratio would be more favorable to cast iron, although the arc-welded steel would still be very much cheaper. However, arc-welded steel has one very great advantage over cast iron, and that is, that the inventory cost necessary for a given production will be enormously decreased. Therefore the item of inventory will be decreased by this substitution. Also, the items of patterns, pattern storage, and repair will be entirely eliminated, which also will very greatly affect inventory.

In general, it is safe to say that the items which would reduce overhead would be largely balanced by the increase necessary because of the increased labor cost, so that the total actual figure in both cases, including overhead, would probably, as an average, balance. This is an estimate only, but it indicates what the company with which the author is identified has found to be true.

Much work must still be done in getting the best shapes and the best method of applying these shapes to the work in hand. In the case of buildings there is still much to be done in the design of the joint for most efficient application of the new process, and also in the methods of erection, which become a very serious problem in arriving at the most economical one possible.

ARC WELDING APPLIED TO PIPE MANUFACTURE.

Another application which is just beginning is the manufacture of pipe by this new process. The advantages here lie in the fact that both the diameter and wall thickness can have any dimensions that are required, and that the material used can have a very wide range of specification without the cost being probably more than two-thirds that of tube-mill or riveted pipe. Because of this, pipe lines in the future will undoubtedly be welded in the making of each section itself as well as the sections welded together in the field.

At the present time a number of arc-welded water lines have been completed, some of them running up close to 100 miles in length, and having diameters ranging up to 6 feet. Yet it is probably safe to say that the average engineer would still put in riveted or lock-bar pipe because that is what has always been put in, in spite of the fact that the new welded-joint procedure will save much money and make a very much more efficient line.

INCONSISTENCY OF PERMITTING ARC WELDING IN SUPERHEATERS OR STEAM PIPING BUT NOT IN BOILERS.

This attitude of mind is probably best illustrated by the present practice in connection with high-pressure superheated steam. The steam must be generated in boilers which are riveted (because state laws permit no other process than riveting being used in a boiler shell), however, the superheater cannot be made tight by rivets because of the very much higher temperature at which it is operated. Also, the steam piping running from the superheater to the turbines cannot be made tight except by arc welding. Therefore we have the rather anomalous situation of the boiler generating the steam being riveted, and the superheater and piping operating at exactly the same pressure but at a higher temperature, being welded.

Another illustration of the same rather unique point of view is shown in the common locomotive. The Interstate Commerce Commission allows very wide latitude in the use of arc welding on locomotives, and there are few locomotives in existence at the present time on which there has not been a very considerable amount of arc welding done both in its manufacture and repair. As is well known, locomotives carry 200 pounds steam pressure, are hand fired, and are racked over the rails at sixty miles per hour. Yet under these conditions very few cases of weld failure have ever occurred, and arc welding has, in the opinion of many railroad companies, increased enormously the amount of time that a locomotive can be kept outside of the repair shop. Yet if one of these welded locomotive boilers is removed from the rails, put on a brick foundation, automatic-stoker-fed, and run at 16 pounds pressure, its owner will be put in jail.

If an arc-welded boiler should explode tomorrow morning and kill a man, it is safe to say that the fact would be broadcast from one end of the country to the other by a number of journals. The fact, however, that on an average there is one man killed every day by the explosion of a riveted boiler, does not even gain passing notice. This is not cited as an argument in favor of welding, but merely as a fact.

Practically without exception every automobile depends for its success on electric arc welding, and if the electric welds failed in service most automobiles would be wrecked, with enormous loss of life. In fact, it is safe to say that practically no automobile (with the exception of the Ford) is in operation today which does not have such parts of it arc welded that if a weld failed a serious accident would result.

Many automobiles not only have the rear-axle housing completely made by arc welding, but in almost all cases also the driveshaft and brake hangers, thus the ability to start, run, stop, and stay on their wheels all depends on arc welding.

It is safe to say that if arc welding in the automobile industry were found defective, it would be ten times more destructive to life than if all the boilers in the country were to explode at once.

The author is citing these cases in the hope that engineers may be led to take a logical view of this great question. It is certainly true that if arc welding is dangerous it ought to be eliminated in any place where its failure will endanger life, but it certainly is a very poor recommendation for engineers and the engineering profession to allow conditions to exist such as are

existing at the present time in which arc welding is eliminated from a boiler shell but used in the superheater of the same boiler; where arc welding is eliminated from air receivers but is used completely in a cracking still; where arc welding is satisfactory on a locomotive boiler but unsatisfactory and forbidden by law in a stationary boiler; where arc welding is prohibited by law from being used in a tank car but specified in the tank into which the tank car is emptied.

The engineering profession is founded fundamentally on logic; if an engineer is not logical, to whom, then, shall we turn?—"Mechanical Engineering," Mid-May, 1927.

THE MANGANESE POSITION.

Not the least interesting part of the proceedings of the spring meeting of the Iron and Steel Institute was a lengthy discussion upon the world position in general, and the Empire position in particular, relating to manganese. This discussion arose upon one of those comprehensive papers which we have come to associate with Sir Robert Hadfield bearing the title "The Metal Manganese and Its Properties; Also the Production of Ferro-Manganese and Its History," in which a most useful survey was given not only of the properties of the metal but of the distribution of manganese ores throughout the world, and this latter may be regarded for the moment as the more important portion of the paper. It is interesting to know that Sir Robert Hadfield was himself responsible for the first of the literature regarding manganese when he read his papers as far back as 1888, and all will join in the congratulations that were offered him on being able, no fewer than 39 years later, to make further important contributions to this subject.

The international position as regards sources of manganese has attracted attention for some years, and there appears to be something of an international scramble among the leading industrial nations of the world to secure supplies. America perhaps seems the most severely hit, as is evidenced by the recommendation of a special committee which has been considering the matter out there that manganese should be purchased in the open market over a period of years with the object of accumulating a stock of 600,000 tons as a reserve in cases of national emergency. On the other hand, the British Empire is fairly well situated if only the deposits distributed throughout the Dominions are properly worked. In the meantime the fact cannot be overlooked that the Americans are endeavoring to obtain control of manganese ore deposits in one part of the British Empire in particular—namely, West Africa—and this action recalls the successful policy adopted by Germany before the war in obtaining control in the British Empire of deposits of essential materials the supplies of which were extremely scarce. At the same time it is satisfactory to record that the statement in Sir Robert Hadfield's paper that the manganese deposits on the Gold Coast of West Africa have now passed into the control of American interests is not the fact, and Sir Robert himself expresses his regret that the error had slipped into his paper. There is some excuse for it, however, because the Americans undoubtedly have been trying very hard to obtain concessions in the Gold Coast, but up till now they have not succeeded in obtaining a single one of any kind. At the moment the control on the Gold Coast is entirely British, but those closely in touch with development on the spot are not unaware of the fact that Americans are building railways near to these deposits, and will, in all probability, make every endeavor to get in first to

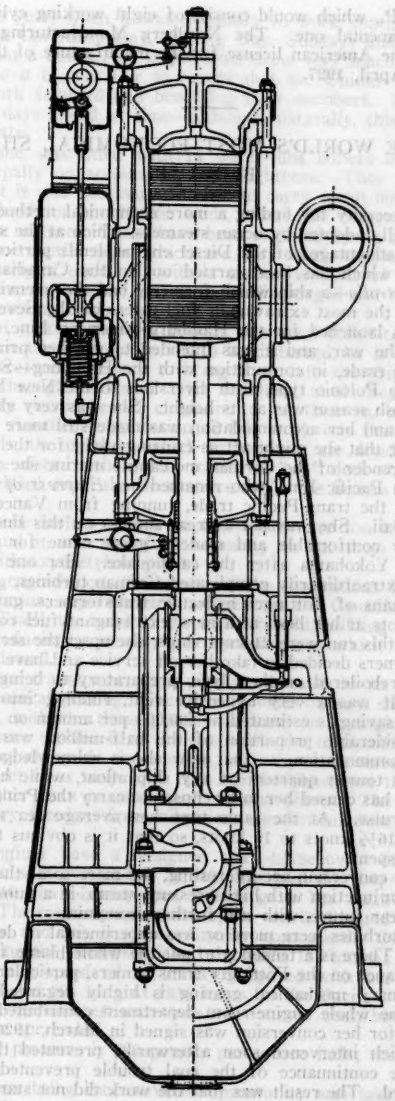
obtain concessions in that British colony. This hint of possible developments, it is to be hoped, will not be lost upon those who are able to take a hand in this aspect of Empire development.

A most important contribution to the discussion on Sir Robert's paper was made by Sir Thomas Holland, who impressed upon us the fact that although the British Empire does possess accessible manganese ores of the right quality, there are difficulties to be overcome before they can be successfully developed, mainly owing to the long distances which the ore would have to be carried if all the smelting was carried out in this country. Great Britain herself cannot produce more than mere samples of manganese ore, and nature's distribution renders it impossible for her ever to do otherwise. We require in this country every year under normal peace conditions something like 150,000 tons of high-grade ores to provide the 50,000 to 60,000 tons of manganese metal now absorbed in steel smelting. Another 50,000 tons, or thereabouts, is required for essentially chemical industries, and until recently we have in this country consumed about 250,000 tons in the manufacture of "ferro" for export. Within the Empire our present two main sources are India and the Gold Coast, and it is anticipated that either could produce enough to meet our requirements if necessary. The journey from India, however, is a long one, and the question was put whether our Government is taking steps to secure a sufficient share of the Gold Coast deposits as a war reserve. It must not be overlooked that apart from West Africa the Americans are reported to be taking an active interest in the deposits recently prospected in South Africa, and once more we find technical men like Sir Thomas Holland, who also have a very wide knowledge of economics, urging institutes like the Iron and Steel Institute to change their policy so that these vital problems of Empire shall not be left solely to politicians. The Empire Congress of Mining and Metallurgy to be held in Canada in August and September this year will have some of these problems under review. It may be that some recommendations will be forthcoming, and the suggestion that our technical institutions should take an interest in the wider aspects of their problems, in order to prevent the simple economic questions from becoming the monopoly of politicians, is one that should receive the fullest possible support from those to whom the advice is tendered. Unfortunately, technical institutions have an extraordinary habit of listening to profound advice of this nature, and the members who hear it are obviously moved; but there it seems to end, no further action of a positive nature being taken by those who control the destinies of our technical organizations.—"Mechanical World," May 20, 1927.

A NEW DOUBLE-ACTING, TWO-CYCLE DIESEL ENGINE.

A number of European oil engine builders have been reported from time to time as experimenting with double-acting cylinders of the two-cycle type in order to develop the type that is apparently destined to prove most suitable for the production of large outputs. Among the latest firms to make public the constructional details of their experimental cylinder is the well known Italian builder of two-cycle engines—Fiat Company, of Turin.

The accompanying illustration shows the cross section of the new Fiat double-acting, two-cycle cylinder of the experimental engine. Its dimensions are: Bore—840 millimeters (33.1 inches), stroke—1,000 millimeters (39.37 inches). This cylinder is reported as having given such satisfactory results that the builders are prepared to accept orders for engines up



to 16,000 B. H. P., which would consist of eight working cylinders identical with the experimental one. The Nordberg Manufacturing Co., of Milwaukee, holds the American license for the manufacture of these engines.—"Ingegneria," April, 1927.

THE WORLD'S MOST ECONOMICAL SHIP.

By F. C. B.

The urgent necessity for finding a more economical method of propulsion than that generally adopted by ocean steamers, which at the same time shall not have the disadvantages of the Diesel engine, lends particular interest to the experiment which has been carried out in the Canadian Pacific liner *Empress of Australia*—a ship which formerly had the unenviable reputation of being one of the most extravagant fuel eaters on the Seven Seas.

This ship was launched for the Hamburg-American Line, as the *Tirpitz*, shortly before the war, and it was intended to use her principally on the South American trade, in conjunction with the Hamburg—South American ships of the Cap Polonio type, with diversions to the New York run when the American rush season was at its height. She was very elaborately fitted for the service, and her accommodation was made still more perfect during the war, in order that she might act as cruising yacht for the ex-Kaiser.

After the surrender of the German mercantile marine she was taken over by the Canadian Pacific Line, who renamed her *Empress of Australia*, and who put her on the trans-Pacific trade, running from Vancouver to Japan by way of Hawaii. She was not a great success on this line, although she was particularly comfortable and made a great name for herself in her rescue work at Yokohama after the earthquake. Her one deficiency was speed, for her extraordinarily complicated German turbines, geared down to the shaft by means of Föttinger hydraulic transformers, gave her a speed of only 16½ knots at her best, at a most extravagant fuel consumption. As her consorts on this run were 21-knot ships, she upset the service badly, and last year her owners decided to take her off service and have her completely re-engined and reboilered on the Clyde, preparatory to being placed on the Atlantic run. It was a very expensive refit, running into half-a-million pounds, but the saving is estimated at £30,000 per annum on fuel alone. In addition, a considerable proportion of the half-million was employed improving her accommodation, so that now she is acknowledged to have the finest third-class tourist quarters of any ship afloat, while her standard of first-class travel has caused her to be chosen to carry the Prince of Wales on his Canadian cruise. At the same time her average sea speed has been increased from 16½ knots to 19 knots, so that it is obvious that the money was very well spent.

Details of her conversion are interesting, the more so as they are likely to be adopted, in conjunction with high-pressure steam, in a number of ships to be built in the near future, with still further economies.

Her original turbines were more or less experimental in design, and were not successful. There is a tendency to put the whole blame for her unsatisfactory performance on the Föttinger transformers, particularly in the areas where the ordinary mechanical gearing is highly regarded. But this is scarcely fair; the whole engine-room department contributed.

The contract for her conversion was signed in March, 1926, but the General Strike, which intervened soon afterwards, prevented the work being started, and the continuance of the coal trouble prevented the materials reaching the yard. The result was that the work did not start until towards

the end of the year, when it was necessary to work continuous shifts—the men putting in Christmas Day, Boxing Day, Sundays and all. The result of this was that a number of shipwrights drew very much more than their foremen, while it is only fair to record that the Unions helped loyally in getting the work forward and benefiting their members. She was actually delivered five days ahead of time—although, naturally, this speed made the work very costly.

Originally she was fitted with 14 water-tube boilers of German Navy pattern, principally on account of their lightness. They saved weight so effectively that it was necessary for her to carry about 800 tons of ballast in her lower holds on the Pacific trade, where the cargoes were generally of a very light nature. These have been replaced by 13 Scotch boilers of the ordinary mercantile type, which are very much simpler to handle, and whose extra weight, combined with a certain amount of extra weight in the engine-room, permits the ballast to be discharged and the ship to go to sea with full-earning holds.

The work of getting in these boilers was very difficult, for her owners would not allow the accommodation to be disturbed, as is usually the case, and it was therefore necessary to bring them into the ship through No. 1 hold, cutting through bulkhead after bulkhead until they were in place. There was only two inches of clearance to get them in, but it was finally accomplished. Another complication of this work was that it all had to be done backwards, the uptakes—which in her case are divided, in order not to interrupt the vista of the public rooms on "A" deck—being put in first and then suspended from the deck above while the boilers were rolled into place.

The water-tube boilers that were taken out were too big to be handled in this way, and it was therefore necessary to cut them in pieces in the ship herself with oxyacetylene plant.

It is in the engine-room that most of the innovations have been introduced, Mr. Johnson, superintendent engineer of the Canadian Pacific, working with Mr. Traill, the head of the Fairfield Shipbuilding and Engineering Company, introducing a number of new practices which are likely to be extensively followed.

The Föttinger transformer has disappeared and in its place is single-reduction mechanical gearing. The three turbines on each shaft are arranged clover fashion, with the three pinions working on a single big gearwheel. The high-pressure turbine is at the top, while the intermediate-pressure and low-pressure are alongside one another, with the stern turbine incorporated. The whole is set on a very solid cast-iron bedplate, and the installation is very much higher than is usual with turbine plants. The result has been an extraordinary freedom from vibration, conspicuous even at the end of a shaft tunnel.

The new engines have a designed shaft-horsepower of 20,000 at 125 R. P. M., with a safe overload to 21,000. On trial the *Empress of Australia* developed 20,440 shaft-horsepower, which gave her an average speed of 20.345 knots. The consumption at this speed was 0.96 pound per shaft-horsepower per hour, and this is extraordinarily economical. On ordinary service, and excluding the "hotel services," she burns 150 tons of oil fuel per day, at an average sea speed of 19 knots, compared with her best day—very seldom attained—of 205 tons, at 16½ knots, in the Pacific. It may be mentioned that the German estimate was 240 tons of coal, but she was never tried before her surrender.

The working pressure is 220 pounds per square inch; the superheating is 240 degrees F.

While she was being reconstructed opportunity was taken to change the screws and design a new pair, after many months of test in the tank main-

tained by the National Physical Laboratory, at Teddington. An innovation is that they were changed from outward to inward turning—a practice which appears to have little enough in precedent to recommend it. There was very considerable opposition to this change, but the tank test showed up so well, both for economy and speed, that the change was made. It would almost appear that the trouble formerly experienced was due to faulty design of the screws, for in the *Empress of Australia* it has approached perfection, and there is certainly none of the unhandiness which formerly handicapped the system.

Perhaps a certain amount of the economy is effected by the extraordinarily complete checking system which has been adopted in every department of the engine-room. Weight and temperature are checked at every step, and the result appears to be very promising.

The auxiliary machinery, also, is right up to date in every particular, the most interesting feature being the new balanced-type Diesel generator. The objection to Diesel generators is usually that they cause considerable vibration, some ships giving the impression that they are under way while they are still alongside the quay. The new type, however, runs like a sewing machine, which adds greatly to the comfort of the passengers. One of the old turbo-generators is kept in the engine-room as a reserve, but it is not anticipated that there will be much necessity to use it.

The economy shown during the trials of the *Empress of Australia* and her initial cruise has been so great that it is expected that the arrangement of her machinery, already incorporated in the plans of the new cabin ships for the North Atlantic service, will be extensively copied by other lines. Certainly it is remarkable, and as there is nothing in the installation to increase the initial cost to any great extent over the ordinary geared-turbine plant, it has this great advantage over the Diesel system, whose high initial cost is its principal handicap.—"Mechanical World," June 24, 1927.

NOTE: See also "Engineering," June 17 and 24, 1927.

THE SCIENTIFIC METHOD.

In its evolvement, this statement has gone through many revisions. Its present form is approved by so many who have done successful research work that its acceptance as a true description of the scientific method is justified.

This statement will be of utility in all departments of science in high schools and in colleges as a means of instruction. Students can place copies in their science note books for frequent reference. It will be useful to graduate students as a guide in self-training in the fulfillment of the scientific method, and to all research workers in planning and carrying through experiments, also in evaluating the scientific quality of the researches of others.

MILTON FAIRCHILD.

10 May, '26.

The scientific method necessitates intensive, systematic and persistent brain work under control against misunderstandings, superficiality and bias, and in complete loyalty to reality and the truth.

None but those having aptitude, instruction and training can be successful in the use of the scientific method of thinking.

DESCRIPTION OF THE METHOD.

(1) Gather data on the problem or within a selected field according to some adequate, sound plan by means of numerous and accurate observations

made with the human senses, assisted and corrected by instruments of precision. The observations are usually with a well-defined purpose but sometimes for information according to opportunity. Observations must be recorded in definite terms and measurements and in specific statements. Many observers may collaborate in gathering data.

(2) Classify and organize data on the basis of similarities, variations, activities, processes, causes, results. Distinguish between essential and superficial characters.

(3) Generalize to get principles and theories into tentative form. Use constructive imagination, discernment, known principles to formulate reasonable generalizations that solve the problem or explain the known facts in the selected field. Many researches accept a mass of classified data and verified generalizations and then proceed to solve some problem by formulating hypotheses thereon and verifying these, without including general gathering of data and classification work.

(4) Verify generalizations by controlled experiments, by tested predictions of results, by repetition of experiments and the gathering of additional data. Appraise data by coefficients of variations and of correlations, and by probable error. Determine sources of error in method and apparatus, and evaluate by auxiliary investigations. State all assumptions and include them in the conclusions.

(5) Report the research in full and subject results to criticism and verification by others competent to collaborate.

(6) Announce the results of the research to the general public for practical use.

THE CHARACTERISTICS OF THE SCIENTIST.

(1) Sincere and open-minded; not diverted by personal interests.
(2) Alert and alive to truth, vital; not complacent.
(3) Poised; not excitable, hysterical or melancholy.
(4) Discerning and thorough; not superficial.
(5) Accurate; not indefinite.
(6) Inventive and constructive; not lacking initiative.
(7) Independent; not suggestible.
(8) Thoughtful and persistent; not merely impulsive.
(9) Industrious and energetic; not lazy and dilatory.
(10) Executive; not haphazard.
(11) Purposeful; not led merely by likes and dislikes.
(12) Self-confident; not timid.

RESEARCH ON HUMAN BEINGS.

A science is any area of knowledge which has been defined and assigned by common consent for intensive study to a group of scientists who by accurate and thorough observation accumulate a mass of applicable data which they classify and organize and on the basis of which they make and verify generalizations as knowledge constituting their science. Some of the human sciences are: anthropology, sociology, psychology, physiology, education. The nature sciences are very numerous and new subdivisions are created when intensive research in a restricted area is inaugurated.

It takes many generations of scientists to mature a science by the use of the scientific method, cooperating from generation to generation. The evolvement of the sciences is a perpetual undertaking, the objectives of which are knowledge and the use of knowledge for human welfare, the maturing and perfecting of civilization.

All the basic principles of scientific research must be fulfilled in human research in order to achieve verified generalizations. A "survey" results in

a description of a situation, a discussion of the same and advices for use in view of the situation, but a "research" to be positively successful has to produce knowledge or solve a problem, by verifying a tentative generalization or theory which has been gotten by induction from reliable data. Research work is the basis of human science as well as of nature science.

The characteristics necessary for success in nature science research are also essential to the human science research workers, and the intellectual immoralities listed as obstructions in nature research must be avoided in human research with even more care, since more dependence has to be placed in human research on the personal judgment of the observers and the reasoning has to deal with very complicated situations.

THE HUMAN BEING A UNIT OF LIFE.

A human being is a unit of life, and even though made up of nature material, differs in one respect, radically, from a chemical substance, a mechanical structure or an animal, in that an active brain of developed powers furnishes this unit of life a self-direction which interferes with the simpler sequences of causes and reactions which prevail in nature science fields of research.

Causes active in pre-natal life, in childhood or in youth may not produce their effects on a human being completely until maturity of life has been attained, and activities in adult environments are being carried out. Children are born into organized groups of adults—home, town, city, state and nation—and are profoundly influenced during development in conduct and character by the culture of these groups. Dormant brain powers come out into full activity late in life sometimes, and there is apparent sometimes a group stimulation of action involving many persons. In national life the results of causes influencing one generation may not appear until the following generation is in control.

GATHERING DATA IN HUMAN SCIENCES.

Data in the human sciences can be gathered with reasonable reliability by using trained discernment in observations by the human senses. Any given research must be under the leadership of a specialist with knowledge and experience in the field of science in which the problem lies, and with research ability. Photography, the dictograph and various testing apparatus can be used to assist the human senses. Interviews and introspections can supplement observations of action, emotions, purposes, restraints and urges. Verifications of data by repeated observations and inquiries are essential to reliability. Statistical treatment of data should be allowed only when classes of data are definitely distinguished and the amount of data is adequate and the individual items reliable. Data relative to many individual persons must be accumulated, classified and organized as large masses of data, in order that adequate bases may be established for generalizations in the human sciences.

HUMAN VARIABLES TO BE TAKEN INTO ACCOUNT.

1. Native abilities variables—mechanical skills, intellectual aptitudes, etc.
2. Physical make-up variables—size, height, weight, strength, race, etc.
3. Instincts variables, 13 centers in body organs.
4. Curiosities variables, 6 spheres through the senses.
5. Urges variables, 12 objectives—possessions, knowledge, honors, etc.
6. Characteristics variables, 92 in all—just, sociable, poised, etc.
7. Maturity of personality variables—physical, psycho-development, etc.
8. Personal experience variables—responsibilities, love affairs, hardships, etc.

9. Information variables—observation, reading, conversation, etc.
10. Convictions and beliefs variables—religion, politics, morality, etc.
11. Personal interest variables—engineering, science, human welfare, fine arts, etc.
12. Environment influences variables—climate, friends, nation, etc.

It is impossible to isolate one phase of a human being's life from the totality of its life, and it is unscientific to conduct experiments on one phase in disregard of active causes and variables operative in other phases during the experiments. "Native intelligence" cannot be isolated from personal experiences, acquired knowledge, physical conditions, etc., for purposes of measurement. Comparable groups of human beings cannot be arranged on the basis of "intelligence tests" alone, even assuming that these are reliable for the individual, since variables in curiosities, urges, personal interests, etc., are unequated by these tests of intelligence, and these variables are active in changing intensity and quantity as causes during the course of experiments. The method of "multiple correlations" cannot eliminate variables which have not been measured and are unknown quantitatively, nor is it applicable when causes are not measurable mathematically, as is the case with human characteristics such as emotions and will-power. The "effective intelligence" of an individual at a given moment and under the circumstances can be measured relative to standard tests, but the results will not distinguish from each other the numerous component causes of brain power nor be reliable for other times and circumstances. "Controlled experiments" after the type of nature science experiments are as yet impossible on the major human problems.

COLLABORATION NECESSARY.

There are numerous human sciences, which have been developed in accordance with teaching and research requirements, but these have not yet been organized into a complete system for research work on human problems. The interaction of causes producing human conduct may be illustrated by combining the action of several pendulums in directing the motion of one central stylus. The innumerable variables active in the human personality are a set of harmonic pendulums all swinging at once, with varying speeds and directions, to produce the action of the individual at any given moment. These human variables represent even a higher level of complexity than mechanical pendulums, since a self-active brain is a part of the human mechanism. Because the human being is a unit of life and cannot be divided into isolated and independent fields of research, it will be necessary to arrange for thoroughly organized collaboration among human science research workers, so that the interaction of causes within the human personality may be appreciated relative to all human problems—physiological, psychological, sociological, genetiç, ethnological, educational, et cetera. Collaboration among human scientists is essential to successful human research in order that knowledge of these many pendulum combinations of causes may be available during experiments on human problems. The different areas for the gathering of data which belong to the various human sciences should be defined, and basic problems chosen in each of the human sciences for persistent research—the collection of data, the classifying and organizing of data, the discovery of tentative generalizations and the thorough verification of theories.

VERIFICATION IN HUMAN SCIENCES.

Tentative generalizations must be valued merely as opinions until verification has been accomplished. Experiments on a small scale, carried out under trained leaders, on scientific plans, and prolonged for a sufficient time, under

normal conditions and when real motives are operative, repeated again and again with uniformly desirable results, will constitute a verification of plans for human welfare. These small-scale experiments should be planned on thorough studies of the situations to be improved, and according to mental calculations on all the discoverable causal factors of human welfare.

INTELLECTUAL IMMORALITIES.

(1) Carelessness in observations, "sloppy work."
(2) Inaccuracy in determining units to be counted in statistical research.
(3) Slovenliness in logic, fantastic explanations.
(4) Generalizing beyond one's data.
(5) Confusing opinions with knowledge.
(6) Confidence in the results of research in disregard of weakness in proof and verification.
(7) Contentment with "discussion."
(8) Poor judgment in research plan and procedure.
(9) Wavering interest, flitting attention, attracted by peculiar superficialities.
(10) Egoism allowed to crowd one to the invention of "new" theories for personal distinction.
(11) Inventing interesting theories for the sake of selling them in books, articles, lectures and conversation.
(12) Pride allowed to result in persistent belief in a theory for which one has been given credit.
(13) Formulating an hypothesis on weak bases of facts, and then becoming blind to facts in opposition.
(14) Emotionalism during research, "I believe" instead of "I have proved."
(15) Adjusting theories to popular likes and dislikes.
(16) Opposition to proof of another's theories because of jealousy.
(17) Opposition to a theory merely because of ignorance and stupidity, "I can not see how."
(18) Rushing into print with a report of research work that justifies no conclusions.
(19) Degenerating into a propagandist of an unproved hypothesis, instead of being true to the research purpose of discovering the truth.
(20) Cowardice in supporting a verified generalization because it is unpopular and conflicts with selfish interests.
(21) Impatience, unwillingness to proceed step by step through a research.
(22) Indulgence in dense verbiage for the sake of appearing superlearned.
(23) Ignorance of the mechanism of instruments of precision, which results in their use when out of order.
(24) Popularizing tentative generalizations for the sake of personal publicity.
(25) Resort to the authorities, or to sarcasm and ridicule, against data, arguments and verifications.

Letters of advice are asked from all interested, especially covering ways and means for controlled experiments and other verifications in the human sciences.

CHARACTER EDUCATION INSTITUTION,
(Chevy Chase), Washington, D. C.

OBITUARY.

JOHN H. MACALPINE.

Born at Paisley, Scotland, November 3, 1859, and educated in the public schools of that town and at the University of Glasgow, where he had the privilege of being a student under Lord Kelvin, Mr. Macalpine spent the latter half of his life in the United States, where he died in Mount Vernon, N. Y., May 31, 1927.

His course at Glasgow was eclectic and did not lead to a degree but he displayed the remarkable talent for mathematics for which he was specially noted, and received many first prizes in various subjects. On graduation in 1879, he entered the engineering department of Robert Napier and Sons, where he was trained under Dr. Alexander Kirk, who gave the impetus to the triple expansion engine by its installation in the *Aberdeen*. He remained at Napiers until 1892, part of the time as assistant to Dr. Kirk. In 1889-90 he went to Russia to supervise the installation of the machinery of the *Sinope* of the Russian Navy which had been built by Napiers.

He came to the United States in 1892 with letters to the late John Beavor-Webb, designer of the yachts *Genesta* and *Galatea*, contenders for the American cup, and later a consulting naval architect in this country. Through him, he met the late Admiral Melville who formed a very favorable opinion of his ability, and recommended him to Senator McMillan of Michigan who was part owner of the Detroit Dry Dock Co., and was looking for an engineering manager. He was appointed to this position and filled it for some time. He was very energetic and endeavored to apply the methods with which he was familiar as best calculated to secure efficiency and economy. Following his service at Detroit he spent some time in the Bureau of Steam Engineering under Admiral Melville, where his familiarity with the best European practice and his own ability enabled him to render useful service.

He returned to Scotland in 1898 and was there until 1902, part of the time with Blackwood and Gordon of Port Glasgow. He also devoted much time to the matter of balancing reciprocating engines, of which he made a careful study and became recognized as an authority. Here, his mathematical talent made this very difficult subject for the average engineer an enjoyable problem for him.

In 1902 he came again to the United States, which was henceforth his home for the remainder of his life. He was engaged in work as a consulting engineer, at first alone and from 1904 to 1909 as a partner of Admiral Melville, after the latter's retirement from his long term of sixteen years as Engineer in Chief of the Navy. He advised the firm of Harlan & Hollingsworth with respect to eliminating vibration in the destroyers *Hopkins* and *Hull* with good results.

Admiral Melville was a close friend of George Westinghouse, who was developing the Parsons turbine in the United States, and who discussed with him its adaptation to marine use. It was evident to all marine engineers that the direct turbine drive was hopeless. In the case of the *Mauretania* and *Lusitania* it was stated by the designers that there would be no increase of economy nor decrease of weight. It was also evident that some means must be devised to permit the economy of the turbine at high speed to be combined with the proper low speed for efficiency of the propeller. Admiral Melville had faith in mechanical gearing, and was the first to advocate it as the simplest and most efficient method—in which opinion experience has proved him to be right. Careful study of the problem by the Admiral and Mr. Macalpine convinced them that, on account of the lack of rigidity in marine structures, there must be provision for elasticity and lack of adjustment, and this led to the invention of the "floating-frame" reduction gear. This was submitted to Mr. Westinghouse, who appreciated its merits, and agreed to bear the expense of experimental development and test with the exclusive option of making an agreement with them after the test. Gearing to transmit 6000 S.H.P. was built and tested out at the Westinghouse Machine Co. with great success, whereupon the agreement was made for its exploitation. This is not the place for the whole

history of the "reduction-gear," but, for historical record, mention should be made that the gear was installed and tried out on U. S. S. *Neptune* in the early part of 1911, and before the trials on the S. S. *Vespasian* of the gear designed and built by Sir Charles Parsons. The Westinghouse Gear and Dynamometer Co. became sole owners of the patents, having purchased the interest of Admiral Melville's heirs and made a royalty arrangement with Mr. Macalpine.

It will undoubtedly interest engineers generally to know the extent of the use of the Melville-Macalpine Reduction Gear, and, through the kindness of Westinghouse Electric Co., the following data have been furnished. That company has made 325 marine installations (naval and merchant) aggregating nearly 2,200,000 S.H.P. Included in these figures are installations in the Swedish and the Japanese navies; in the latter there are four units of 40,000 S.H.P. each, the largest single reduction gears ever built. Licenses have been taken for the Japanese Navy and by Metropolitan—Vickers Co., of England, and data are not available of all the installations made under these licenses. Three of the ships fitted in the U. S. Navy are the Scout Cruisers built by Todd of about 100,000 S.H.P. each. The high efficiency of these gears (and the very low friction) is shown by their long life. Over seventy-five per cent of the marine installations are in actual operation at this time; some units have logged over seven hundred thousand miles without replacement, and a large number have made more than three hundred thousand miles.

Besides marine work, the gears are used for driving large D. C. generators, compressors, etc., in land plants, and there have been 158 installations of this kind, aggregating nearly 200,000 S.H.P.

Mr. Macalpine was associated for a time with the Westinghouse interests as a consulting engineer, and later continued this work on his own account. He was a contributor to the engineering press on matters relating to reduction gearing, balancing, and other marine subjects.

In 1892 he married Miss Mary J. Coats, of Paisley, who survives him with a daughter and two sons.

ASSOCIATION NOTES.

The following members have joined the Society since the publication of the May, 1927, JOURNAL:

NAVAL MEMBERS.

Abbott, Royal W., Lieutenant, U. S. Navy.
Anderson, Charles C., Lieutenant, U. S. Navy.
Bedford, Stephen R., Ensign, U. S. Navy.
Carlisle, Harold A., Lieutenant, U. S. Navy.
Couble, Alexander J., Lieutenant, U. S. Navy.
Cross, Richard F., Lieutenant, U. S. Navy.
Detzer, August J., Lieutenant, U. S. Navy.
Dingwell, John E., Lieutenant, U. S. Navy.
Dockweiler, Edward V., Ensign, U. S. Navy.
Dufton, Walter S., Lieutenant, U. S. Navy.
Edelman, Leighton M., Lieutenant, U. S. Naval Reserve, 161 Lake Avenue, Piedmont, Calif.
Endom, Eugene S., Lieutenant Commander, U. S. Coast Guard.
Fielding, Charles F., Lieutenant, U. S. Navy.
Gearing, Hilyer F., Lieutenant, U. S. Navy.
Giles, Donald T., Lieutenant, U. S. Navy.
Godfrey, Vincent H., Lieutenant Commander, U. S. Navy.
Granbery, George M., Ensign, U. S. Navy.
Guard, Joseph A., Lieutenant, U. S. Navy.
Hanson, Edward W., Lieutenant Commander, U. S. Navy.
Hatch, Maurice E., Lieutenant, U. S. Navy.
Hatcher, Robert S., Ensign, U. S. Navy.
Hoffman, Charles M. E., Ensign, U. S. Navy.
Houghton, Royal A., Lieutenant, U. S. Navy.
Howard, William B., Jr., Ensign, U. S. Navy.
Hudson, Roy C., Lieutenant, U. S. Navy.
Isbell, Arnold J., Lieutenant, U. S. Navy.
Isgrig, Clayton S., Lieutenant, U. S. Navy.

Jeffs, Charles R., Lieutenant, U. S. Navy.
Juvenal, William W., Lieutenant, U. S. Navy.
Kelley, Marion R., Lieutenant, U. S. Navy.
Kelly, Thomas J., Lieutenant, U. S. Navy.
Kidd, Alexander C., Ex-Lieutenant, U. S. Navy, care Chisholm, Moore Mfg. Co., Lakeside Avenue, Cleveland, Ohio.
Kohrs, Franklin B., Lieutenant, U. S. Navy.
Lamdin, Charles R., Lieutenant, U. S. Navy.
Lyttel, George H., Lieutenant, U. S. Navy.
Noble, Christopher, Lieutenant, U. S. Navy.
Noble, Kenneth H., Lieutenant, U. S. Navy.
Paré, Edward E., Lieutenant, U. S. Navy.
Parfitt, Thomas A., Lieutenant, U. S. Navy.
Poole, Elwood D., Lieutenant, U. S. Navy.
Price, William S., Lieutenant, U. S. Navy.
Rees, William L., Lieutenant, U. S. Navy.
Reuse, Harry J., Lieutenant Commander, U. S. Navy.
Richmire, George L., Lieutenant, U. S. Navy.
Roberts, Walter H., Lieutenant, U. S. Navy.
Robinson, Robert E., Jr., Lieutenant, U. S. Navy.
Sihler, William, Ensign, U. S. Navy.
Stoddert, Francis B., Lieutenant, U. S. Navy.
Talbot, Frank R., Lieutenant, U. S. Navy.
Taylor, Francis, Lieutenant, U. S. Navy.
Tellman, Herbert A., Lieutenant, U. S. Navy
Thompson, Edward M., Lieutenant, U. S. Navy.
Ward, Benjamin N., Lieutenant, U. S. Navy.
Wegforth, John F., Lieutenant, U. S. Navy.
Welborn, Charles, Jr., Lieutenant, U. S. Navy.
Wells, L. E., Lieutenant Commander, U. S. Coast Guard.
Woodside, Elmer L., Lieutenant Commander, U. S. Navy.
Woodson, Charles P., Lieutenant, U. S. Navy.
Zimmerli, Rupert M., Lieutenant, U. S. Navy.

CIVIL MEMBERS.

Hampton, Wade E., 802-804 Biltmore Hotel, Los Angeles, Calif.

Kavanaugh, Dennis, Jr., Post Graduate School, Naval Academy, Annapolis, Md.

Wilbur, Ralph S., Post Graduate School, Naval Academy, Annapolis, Md.

ASSOCIATE MEMBERS.

Barreto, Barros, Jr., Lieutenant, Brazilian Navy.

Loveren, Harold W., University of New Hampshire, Durham, N. H.

BACK NUMBERS OF JOURNAL.

The Society desires to obtain the following numbers of the JOURNAL:

Vol. I, Nos. 1, 2 and 4.

Vol. II, No. 1.

It is requested that any one desiring to dispose of these numbers inform the Secretary, stating price at which they will be sold.

XU